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ORIGINAL ARTICLES.

The Petrology of Sark.

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It has long been known that the Island of Sark contains a well-developed group of schistose rocks, comparable with those of Start Point and the Lizard. The consideration of the earlier literature of the subject need not detain us here ; it is referred to by Bonney and Hill in their papers quoted below.[1] It is to the latter writers that we owe our present knowledge of the nature and distribution of the schistose rocks with their accompanying plutonic intrusions, and for a general description of the Island the reader is referred to their account. Since, however, they were primarily interested in the general question of the origin and nature of metamorphism—a question then bulking largely in geological controversy—they undertook no detailed petrographic description of the rocks. It seems desirable that such a description should now be attempted, for the rocks present features of no little interest. Moreover it is possible to institute a close comparison with the rocks of S.W. England and of Brittany, and thus to demonstrate the existence of a group of rocks which retains almost identical features over a wide area and which should prove an invaluable datum-line in interpreting the structure of the Armorican Massif.

Summarily it may be stated that four series of rocks, in more or less vertical superposition, can be distinguished in the cliffs of the island, viz. :—

4. Mica-schists and granulites.
3. Hornblende-schists and amphibolites.
2. A heterogeneous igneous complex showing primary gneissic banding and consisting of hornblendite and aplite.
1. Slightly gneissose dioritic and granitic masses.

There are in addition numerous dyke rocks of later date, including lamprophyres, porphyrites, and dolerites. These rocks present no features of special interest and will not be included in the following account.

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[1] E. Hill, *Q.J.G.S.*, vol. xliii, 1887, pp. 322–35 ; T. G. Bonney and E. Hill, *Q.J.G.S.*, vol. xlviii, 1892, pp. 122–44 ; also T. G. Bonney, *Q.J.G.S.*, vol. lxviii, 1912, p. 55.

The arrangement of the four rock groups noted above does not, of course, imply a simple stratigraphical relation ; it merely expresses the facts observed. At every accessible point at the base of the cliffs a coarse-grained, slightly gneissose plutonic rock is seen. Similar rocks form the major part of Little Sark (the southern extremity of the island), the northern part of the main island and the western half of the neighbouring island of Brechou. It is clear that these plutonic bodies have risen into, enveloped, and in part assimilated the overlying rocks whose original base is thus for ever lost. An acid differentiate of the intrusive magma has been extensively injected into the schists as veins and sills following the foliation. It thus appears that the metamorphism of the schists antedated the intrusion, but local puckering and granulitization of the intrusive veins indicates that there was also a later period of movement.

The hornblendite-aplite complex is graphically described by Bonney and Hill. It certainly owes its origin to the streaking out of a heterogeneous magma, but its relations are far from clear. It antedates the plutonic bodies below, but appears to pass upward into the hornblende-schists above. We prefer at present to maintain a frankly agnostic attitude in regard to this group, pending further work, and it will not receive detailed consideration in this paper.

The hornblende-schists are the dominant and characteristic rocks of the island. They form the greater part of the cliffs, but pass upward into mica-schists. The inland range of these two groups is difficult to trace owing to the paucity of exposures. The area of their outcrop is, however, somewhat exaggerated in the published map. Apophyses from the underlying plutonic mass are not infrequently seen on the tableland which forms the central portion of the island, and such rocks might be found to occupy considerable areas if the exposures permitted of an accurate survey.

THE SCHISTS.

As pointed out above a rough twofold division of the schists into hornblende- and mica-bearing types is possible. It will be convenient to retain this division for purposes of description, though the two types grade into one another.

The hornblende-schists as seen in the field are dark green or black rocks showing a well-marked banding, which simulates stratification, and was indeed interpreted as such by Hill in his original account. This banding, as will appear in the sequel, is due in part to mineralogical variations within the schists themselves, but the effect is augmented by innumerable sills and veins of aplite, pegmatite and granite injected along the foliation, in addition to venules of epidote and quartz which follow the same direction. In the mass the rocks are lithologically monotonous, and but few distinct types can be recognized by macroscopic characters.

Under the microscope the rocks are seen to be essentially aggregates of hornblende, plagioclase, quartz, and epidote. Sphene, apatite, and iron ores are conspicuous among the accessory minerals, and there are in addition secondary products of alteration and pneumatolysis.

The rocks vary somewhat widely in coarseness of grain, though this is not readily apparent in the hand-specimen. They normally show a very perfect foliation of the " closed " type, but certain varieties are granoblastic in texture, and hence are more appropriately named amphibolites. There is sometimes a slight suggestion of blastophitic texture. The dominant minerals have the following characters. The hornblende shows sub-idioblastic outlines, and is of a deep green colour. The extinction is normal and the pleochroic scheme as follows :—

x=pale yellowish green.
y=z=dark bluish green.

The bluish tints suggest the presence of the glaucophane molecule.

The quartz and felspar are xenoblastic occurring as fairly equidimensional grains, or as phacoids aligned with the foliation. The quartz is often full of " regular " inclusions, i.e. acicular crystals of definite mineral species. The felspar is invariably a member of the soda-lime series, and shows both albite and pericline twinning. Untwinned grains are rare or absent. It ranges in composition from albite to andesine, sodic types predominating. It is in general extensively altered, the albite molecule appearing as a mesh of paragonite laths while the lime-rich varieties are masked by a dense saussuritic aggregate.

Epidote is present in diverse forms. To a limited extent it occurs as a primary metamorphic mineral, being associated with the hornblende in clusters of feebly tinted grains. It also occurs as an alteration product of hornblende, appearing particularly along the cleavages of the latter. The dominant mode of occurrence, however, is in veins with quartz, zoisite, and clinozoisite. These veins are frequently oblique to the foliation and merge into streaks and patches of epidosite very prominent on the weathered surfaces of the rocks. The epidote which occurs in this manner is much more highly coloured, and presumably richer in iron than that mentioned above.

Both apatite and sphene are abundant and widely spread in the rocks. The latter is especially deserving of mention for the perfect form and large size of its crystals. The writer knows of no rock in which the mineral is seen to better advantage. Magnetite, pyrites and ilmenite also occur plentifully, the last named often surrounded by an alteration crust of secondary sphene.

The relative proportions of the dominant mineral species vary markedly in the different bands. The commonest type of variation is a regular alternation of hornblendic and felspathic bands. In such cases it is noticeable that the iron ores are almost confined to the felspathic layers. The significance of this fact is not entirely clear, but it may be in part due to heteromorphism. In the more homogeneous type of schist the iron-ore is normally enclosed in, or closely associated with, the hornblende, and it would appear to have been thrown out of combination during the metamorphic changes.

Again there occur markedly quartzose bands in which hornblende is absent, the only coloured minerals being chloritic pseudomorphs after biotite. Such bands, which form a type quite distinct from the normal schists, occur throughout the succession. They are obviously related to the mica-schist above and also to certain dark-grey massive rocks which occur low in the schist succession at La Grève de la Ville and elsewhere. In the latter, hornblende is absent, the rock being dominantly quartzo-felspathic, with shreds and wisps of chlorite after biotite.

It is difficult to resist the impression that the banding of the schists corresponds to an original stratification. The fact that authorities like Van Hise set a very rigid limit to the possible migration of material during metamorphism supports the idea that original differences of composition must inevitably be reflected in the metamorphosed product. It is true that Stillwell has introduced the term " metamorphic differentiation "[1] in explaining certain features of the Adelie Land schists, but his conception, though attractive, has comparatively little evidence in support of it.

There can be little doubt on general grounds that the Sark hornblende-schists represent igneous rocks of basic composition. This proposition is accepted so widely in the case of similar schists in other areas that it is needless to argue the point formally. As shown below, the chemical composition of the rocks is consonant with such an origin. It is, however, relevant to ask which were the sills and which the lavas and ashes of this ancient volcanic series. While it is not possible to answer this question in detail, it may be suggested that the true hornblende-schists such as are seen at Port du Moulin represent lavas with, in all probability, intercalated sills. The quartzose bands may be regarded as metamorphosed ashes or sediments. The occurrence of quartz in schists derived from basic igneous rocks does not in itself demand such an assumption, for silica is set free during the conversion of pyroxene into amphibole. Such no doubt was the origin of the quartz which occurs in the hornblendic bands intimately mixed with the other constituents. Where, however, the proportion of quartz rises markedly, and the hornblende decreases, it seems justifiable to infer an admixture of normal detrital sediment. The massive quartzose schists of La Grève de la Ville are indeed best regarded as sheared felspathic sandstones or arkoses, with perhaps a slight admixture of ashy material represented by the ferro-magnesian constituents.

It is natural to institute a comparison of these schists with the closely similar rocks of Start Point and the Lizard. Bonney has pointed out that the Sark schists are indistinguishable in the hand specimen from those of the Lizard. We note, however, the complete absence in the former of diopside, produced at the Lizard, as in the Mysore schists, by contact metamorphism. Further, in the Lizard schists quartz is subordinate in amount, and the plagioclase appears to be slightly more basic. Nevertheless, the petrographical agreement between the two sets of rocks is very close, the grade of metamorphism being the same in both cases. There is also close agreement with the Start green schists, except for the fact that in Sark the lower grade chlorite-epidote-albite schists are not known at present.

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[1] Stillwell, *Sci. Reports Inst. Antarctic Exped.*, 1911–14, ser. A, vol. iii, pt. i, 1918.

TABLE OF ANALYSES.

	A.	B.	C.	D.	E.
SiO_2	51·68	48·64	49·32	49·06	63·51
Al_2O_3	10·48	14·99	14·82	15·70	14·60
Fe_2O_3	6·63	3·42	3·08	5·38	·89
FeO	7·89	7·76	7·27	6·37	5·04
MgO	7·77	7·76	7·94	6·17	1·26
CaO	9·37	9·60	11·25	8·95	5·40
Na_2O	1·89	3·52	2·54	3·11	3·98
K_2O	·89	·52	·32	1·52	2·96
± H_2O	1·27	1·35	2·39	1·62	1·88
TiO_2	1·62	1·9	1·55	1·36	·52
P_2O_5	n.d.	·16	n.d.	·45	n.d.
MnO	n.d.	·30	n.d.	·31	n.d.
Accessories	n.d.	·29	n.d.	n.d.	n.d.
	99·50	100·21	100·4	100·00	100·04

A. Hornblende-schist, near Creux Harbour, Sark, anal. G. M. Stockley.
B. Hornblende schist, The Lizard, anal. E. G. Radley, *Mem. Geol. Surv.*, 1912, p. 48.
C. Hornblende epidote-albite-schist, Prawle Point, Start, anal. C. E. Tilley, *Q.J.G.S.*, vol. lxxix, 1923, p. 186.
D. Average basalt, Daly.
E. Massive quartzose schist, La Grève de la Ville, Sark, anal. G. M. Stockley.

In the accompanying table, analyses of two of the Sark schists are compared with those of similar rocks from the Lizard and Start Point, and with Daly's average basalt. The agreement of the normal hornblende-schist with its English analogues will be seen to be very close, except in the case of the alumina and ferric oxide. These are, in a measure, mutually replaceable constituents.

THE MICA-SCHISTS.

These rocks are best seen in quarries at the cliff top near Moie de Mouton on the west coast and on the steep southward-facing slope of the "Hog's Back" east of Dixcart Bay. At the latter place it is readily apparent that they occur above the hornblende-schists; there is no well-marked line of division between the two, but a zone of passage in which both types occur interstratified. They may be followed for considerable distances along the top of the cliffs, but their inland range is uncertain. This results from the fact that they weather easily, giving rise to a thick soil, which is rarely penetrated in natural exposures.

As seen in the field the rocks are of striking appearance, comprising bands of fine-grained silvery brown schist alternating with thin granulitic layers rich in felspar. Owing to their superior hardness the latter weather out on exposed faces, and the banded appearance is thus augmented. The general appearance is that of a singularly perfect lit-par-lit injection, but this is not, in reality, the origin of the structure, as will be shown below.

The schistose bands bear a marked resemblance to certain of the Moine types from the N.W. Highlands. They consist of fine-grained aggregates of biotite, quartz, and felspar, with small amounts of garnet. The foliation is well-developed, sheaves and wisps of mica wrapping closely round phacoids of quartz and felspar. The biotite is idioblastic, occurring in blade-like crystals with a high index of elongation. It has a slightly greenish colour and contains inclusions of ilmenite altering to leucoxene, and of rutile. The quartz and felspar are xenoblastic. The former occurs in lenses or streaks showing peripheral granulation. As in the hornblende-schists, it shows a profusion of " regular " inclusions. The felspar, much smaller in amount than the quartz, is chiefly a sodic plagioclase (albite and albite-oligoclase), but a small amount of orthoclase is present. It is noteworthy that a very large proportion of the plagioclase grains show a combination of albite and pericline twinning. Twinning on the latter law is comparatively rare in the hornblende-schists. In form the felspar grains are more regular than those of the quartz ; some are almost idioblastic.

Porphyroblasts of a colourless garnet occur sparingly throughout the schists. They are much shattered, often retaining no trace of their original form. In the shattering process their incipient dodecahedral cleavage has been emphasized and individuals are frequently broken up along these rough cleavage planes and streaked out along the foliation. Each garnet crystal is surrounded by a definite quartzose zone free from felspar and mica, and quartz is included poikilo-blastically in the garnet. It would thus appear that the garnet has resulted from the interaction of the latter minerals, and that silica has been set free in the process. However, the garnet is seen altering to a blue-green chlorite, and this change also results in the setting free of quartz, which was doubtless added to that formed in the other reaction. Since the alteration to chlorite involves a volume increase of over 50 per cent it might be contended that the shattering of the crystals was due to this cause. The facts, however, will not bear this interpretation, since the degree of shattering is independent of the amount of alteration. They must be taken as indicating a definite period of earth-movement posterior to the formation of the schists.

The granulitic bands are composed of the same minerals as the schists, but mica is on the whole subordinate in amount. The rocks are equigranular and relatively coarse, the grains of quartz and felspar averaging about a millimetre in diameter. Superficially the rocks resemble crushed igneous rocks; some indeed may possibly be of that nature. However, the common association of quartz with abundant plagioclase and very subordinate orthoclase is inimical to such an interpretation, and there is much to be said for regarding the rocks as being originally coarse arenaceous material —felspathic sandstones or arkoses. Indeed, taking the series as a whole, we cannot doubt that it represents a normal sediment deposited after the cessation of igneous activity. That it contained ashy material now represented by the ferro-magnesian constituents is to be regarded as probable, but this material would in reality be detrital in origin, derived from the breaking down of pre-existing igneous rocks.

THE PLUTONIC ROCKS.

The extent and general relations of the plutonic masses of Sark have been dealt with on a previous page. In the mass the rocks are of uniform appearance. They comprise white or grey granites and diorites of medium grain. Most of the types examined fall within the definition of the term " tonalite ", as extended by Bailey [1] to include " calc-tonalite " and hornblende-biotite-granodiorite. Some of the rocks, however, are virtually di-mineralic, consisting simply of oligoclase and hornblende, but in the dominant type quartz is present, together with orthoclase and biotite, and these rocks grade into true granites. Field examination has so far failed to indicate any orderly distribution of the several varieties such as would result from differentiation *in situ*. The variation seems to be of a patchy character, quartzose and quartz-free types occurring in close association without any sign of a definite junction between them.

Under the microscope the following features are to be noted. Plagioclase always predominates over orthoclase in amount, and has a composition approximating to that of oligoclase.

The hornblende is closely similar in character to that seen in the schists. It shows simple and lamellar twinning on the orthopinacoid and alters to a bright green highly pleochroic chlorite whose properties agree with those of penninite. As noted by Lacroix and Van Hise,[2] the chlorite is, under these conditions, accompanied by rhombohedral carbonates, quartz, iron-ores, and epidote.

A point deserving of special emphasis is the constant association of hornblende with biotite in the quartzose types of rock. The biotite has every appearance of having been formed from the hornblende since it forms selvages to hornblende crystals and penetrates them ultimately along their cleavages. There occur in the rocks certain minerals which appear to owe their origin to paulopost agencies. Aggregates of zoisite and clinozoisite commonly occur along the intercrystalline boundaries, particularly between hornblende and felspar. There are also veins of close-packed epidote and zoisite granules whose mode of occurrence strongly suggests that they are hydatogenetic veins dating from a late stage in the crystallization-history of the rock. Their presence helps to explain the conspicuous epidote veining of the schists above, which doubtless owes its origin to the same circulating solutions.

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[1] " The Geology of Ben Nevis and Glen Coe ": *Mem. Geol. Surv.*, 1916, pp. 151, 153.

[2] Van Hise, *Treatise on Metamorphism*, p. 287.

The foregoing brief description indicates that some, at least, of the rocks are quite normal and admit of a ready classification. However, a closer inspection of the systematic affinities of certain types reveals difficulties. All the rocks are exceptionally rich in hornblende and many are for practical purposes di-mineralic. In one case Rosiwal analysis indicated 48 per cent of felspar (chiefly oligoclase) and 50 per cent hornblende, and several similar types yielded comparable figures. Such a rock is clearly anomalous. The high proportion of hornblende together with relatively acid plagioclase is a feature not reproduced by normal diorites. In oligoclase-diorites the proportion of hornblende is small; as it increases the rocks grade into labradorite types.

There can be little doubt that these peculiar rocks owe their existence to the assimilation of the overlying schists and of the hornblende-aplite series into which the plutonic bodies have forced their way. An examination of the contacts at all accessible points reveals the fact that the relation of the intrusive rocks to their roof is bathylithic or replacive. Their upward progression has involved the wedging off of huge blocks of schist and hornblendite, which appear in all stages of dissolution. This is particularly well seen at Port du Moulin and Pegâne Bay, on the west coast; again in Dixcart Bay there is abundant evidence of a similar process, indeed the coasts of Sark show numberless examples of arrested stoping, both on the large and the small scale. It is to this cause that the variable thickness of the hornblendite-aplite series is due. In some places it appears to have been almost completely assimilated by the subjacent plutonic body, in others a great mass of it still remains.

Xenoliths of the roof-rocks are numerous within fifty yards of the contacts, but as one recedes from this marginal zone they decrease in number and size. In some cases they are clearly bounded against the enclosing rock and retain the characters of the parent body, but many have been disrupted and scattered as isolated crystals or crystal groups. The invading rock is clearly enriched in hornblende in the neighbourhood of these disrupted xenoliths, but the crystals have every appearance of being spread mechanically without fusion and recrystallization. In portions of the igneous masses remote from the contacts—e.g. at the Eperquerie, no normal xenoliths are seen, but there occur dark ellipsoidal masses rich in biotite, ranging up to a foot in longest diameter. These, as the sequel will show, are to be regarded as modified xenoliths.

Examination of sections cut from xenoliths and from the enclosing rock in their neighbourhood confirms the impressions derived from field-evidence. Near the contacts the xenoliths are often quite unmodified. The first stage in their alteration appears to be the development from the normal hornblende of a secondary actinolitic variety which occurs in bright green needles enclosed in quartz or epidote. The mineral resembles that sometimes produced by contact metamorphism and may be interpreted as due to simple heating. It is noteworthy that no pyroxene is developed at this stage. Concurrently with this partial reconstitution of the hornblende, there is a development of biotite along the lines of contact of hornblende crystals or along their cleavages. Those xenoliths which retain their individuality are found to be progressively enriched in biotite at the expense of hornblende, as they are traced away from the contacts. The final stage of their alteration is represented by the dark mica-rich bodies noted above. The same tendency toward conversion into biotite is seen in the isolated crystals of the disrupted xenoliths. The process of fragmentation can be traced clearly in thin section ; clots of hornblende crystals are seen frozen in the act of breaking up. We have already noted the fact that the hornblende of the intrusive rocks is in part, at least, indistinguishable from that of the schists, and have referred to its constant association with biotite. Such relations have often been interpreted as an expression of the tendency of crystallizing minerals to attach themselves to earlier formed associates and thus to form a rough centric structure. In this case, however, it can hardly be doubted that much of the hornblende of the granites, etc., has been derived directly from the schists, and that reaction with the magma causing conversion to biotite has affected these scattered crystals no less than the discrete xenoliths.

The facts outlined above are in most satisfactory agreement with Bowen's conclusions as to the nature and extent of the assimilation of foreign bodies by igneous rocks.[1] He claims that a magma cannot dissolve inclusions composed of minerals with which it is saturated. Taking the special case of a granitic magma saturated with biotite, Bowen points out that " this magma is effectively super-saturated with olivine, pyroxene, and amphibole, and cannot dissolve them. But the magma can, and will, react with these minerals, and convert them into biotite, usually by steps ". Viewing the process broadly, it may be said that the magma will effect changes in the inclusions which give them a mineral constitution similar to that of the granite. " These changes will often be accompanied by disintegration of the inclusions and the strewing about of the products, which may thus be completely incorporated, though not in any sense dissolved."

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[1] N. L. Bowen, " The Behaviour of Inclusions in Igneous Magmas " : *Journ. of Geol.*, vol. xxx, 1922, p. 513.

The above account of the assimilation phenomena in Sark was complete for some months before Bowen's paper came to the writer's notice, and it has not been modified. The close agreement of the facts with Bowen's general statement is too obvious to need emphasis. It may fairly be surmised that the original magma was saturated with hornblende, but that the biotite phase was imminent. Foreign hornblende crystals were scattered through the mass without fusion, subsequently to be made over in part into biotite.

It is very difficult to assess the extent of the alteration in the plutonic rocks due to assimilation. Daly has rightly insisted that the period of stoping is longer than that of active assimilation, and no doubt, in the present case, the existing xenoliths are but the rearguard of a host, which has been completely incorporated. It is to be noted that Daly explains certain diorites as formed by a syntexis of basalt and granite, and since the hornblende-schists have the composition of basalt, the dioritic modifications of the granite might have resulted from active assimilation in the early stages. In any case, it cannot be doubted that the original magma in Sark was essentially granitic. This being so, it is natural to inquire as to the possible relation in time between this mass and the granites of Jersey. The latter are generally assigned to the late Pre-Cambrian on somewhat flimsy evidence. As to the precise age of the Sark intrusions there is no adequate evidence at all. Since granitic apophyses and sills of aplite are injected along the foliation of the schists the intrusion clearly post-dates the metamorphism. There is evidence of a later period of movement since the sills and veins are locally folded with the schists on a small scale, and occasionally show slight signs of crushing when examined under the microscope. Nevertheless, the intrusions have escaped severe dynamic metamorphism ; their slight tendency to parallel structure is due to piezo-crystallization. In this respect they contrast strongly with their analogues at the Lizard (Man o' War Gneiss, etc.), which show abundant evidence of pressure modification and which are confidently assigned to the Pre-Cambrian. There is nothing to show that the Sark granites are not Armorican in age, and for the present the question must be left open. Much will depend on the age ultimately assigned to the Jersey granites.

CONCLUDING SUMMARY.

It is proposed to offer a few remarks as to the general relations of the rocks described to their associates in the Channel Islands, and in the Armorican Massif generally.

In the first place it may be remarked that the Pre-Cambrian rocks of the Channel Islands, judged simply as lithological groups, afford a singularly close analogy with those of Britain. The volcanic rocks of Jersey recall the Uriconian lavas and ashes, both in petrography and field occurrence. The so-called Jersey shales on which the volcanic rocks rest, are comparable with the Eastern Longmyndian or Stretton series of Shropshire. The Jersey Conglomerate and its presumed equivalents—the arkoses of Alderney—are commonly referred to the base of the Cambrian, but the evidence for this correlation is at best very slight, and need not deter us from comparing the rocks with the Torridonian series, with which they have much in common.

The schists of Sark are clearly immeasurably older than the comparatively unaltered Jersey Pre-Cambrian rocks. They find their closest British analogues in the schistose groups of the Lizard and Start Point, and in certain of the green schists of Anglesey. They are represented in Guernsey by the Jerbourg schists[1] and are probably not widely separated in age from the gneissose rocks of that island.

In pointing out these broad lithological resemblances, we do not wish to imply that definite correlation of the similar groups is possible. It is, however, clear that in the Channel Islands, no less than in Britain, the Pre-Cambrian rocks fall into two natural divisions, the lower one having suffered dynamic metamorphism, while the upper is comparatively unaltered. These divisions correspond in spirit, if not in fact, with the Archaeozoic and Proterozoic divisions of American geologists. As to the relation between the two groups in the Channel Islands, there is but meagre evidence. Farquharson[2] claims that equivalents of the Jersey shales rest unconformably on the Guernsey gneisses, but this does little more than confirm the general inference as to their relative age. The solution of the problem is to be sought on the adjacent mainland in Brittany.

We have already drawn attention to the petrographical similarity between the Sark schists and those of S.W. England; a similarity so close as to render the correlation of the two groups permissible. It is natural to inquire whether similar rocks occur in Brittany. The Sark schists may be regarded as occupying the core of one of the major anticlinal axes of Brittany—the Guernsey-Leon axis. Tracing this axis westward across Northern Brittany, we find no similar rocks marked on the official French map.[3] Immediately to the south is a major synclinal axis running south of Paimpol, succeeded southward again by another anticlinal axis. Along this axis from Runan past Pontrieux to Plouha occur hornblende and mica schists, resting on diorites. The available descriptions indicate that the schists are similar to those of Sark, and their relations to the apparently underlying diorites seem to be the same. It can hardly be doubted that we are here dealing with the same series of rocks. If this correlation is found to be justified, and if the volcanic rocks represented by the schists extended over the whole area, the region of vulcanicity must have been an E.–W. belt 200 miles broad. This would imply that the lavas were the products of fissure eruptions. At present this cannot rank as more than a suggestion. Quite apart from the recent disquieting speculations on continental fragmentation, whereby the several parts of a small volcanic field might be widely scattered, there is the possibility that each of the three areas represents a separate eruptive centre. Nevertheless, the general petrographic character of the hornblende-schists is consonant with the idea of fissure eruptions, as is pointed out by Flett [1] in the case of the Lizard rocks.

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[1] Farquharson, *Q.J.G.S.*, vol. lxxx, 1924, p. 375.

[2] *Q.J.G.S.*, vol. lxxx, 1924, pp. 384, 385.

[3] *Carte Géologique de la France*, Sheet 42 (Tréguier), with marginal "Notice Explicative" by Ch. Barrois and M. Michel-Lévy.

In conclusion, it may be well to point out that much further work remains to be done in Sark. The intention of the present paper has been to deal broadly with the several rock groups, but certain important problems have been left untouched. Further work is in progress which should help to elucidate these matters.

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Is the Chalk a Chemical Deposit?

By Professor W. A. TARR, Ph.D., F.G.S.A., University of Missouri.

1. Introduction.
2. Prevalent Views as to Origin.
3. The Composition of the Chalk.
    (*a*) Organic Materials.
    (*b*) Spheres and Cells.
    (*c*) Amorphous calcareous material.
    (c_1) Composition of the amorphous material.
4. Chemical Composition of the Chalk.
5. The Possible Chemical Origin of the Chalk.
6. Cause of Precipitation.
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8. Summary.

INTRODUCTION.

THE Chalk of England and France has been so often under consideration by geologists of all countries that it would seem useless to call attention to it again. However, geology is too progressive a science for any problem to be considered as definitely decided for all time. Kindred sciences are constantly furnishing new data whose applications to our science often bring far-reaching results. Constant revision in the light of all new scientific advances is essential to the progress of which thus far we justly feel so proud.

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[1] *Mem. Geol. Surv.*, 1912, pp. 18, 19.

The writer has recently had occasion to read a considerable part of the voluminous literature on chalk, especially that relating to its origin. At first he held the view, so widely expressed in all textbooks and published accounts of the chalk, i.e. that it was an accumulation of the remains of foraminifera, mollusca, echinodermata, and other organisms, but, as the details of its structure and composition were followed, it seemed that the prevalent view did not fit the facts. This led to a careful examination of the subject to determine, if possible, whether or not, a part of the material composing chalk was not really a chemical precipitate. The results of that study are embodied in this paper, and are given in the hope that others will read them and take up a detailed study to determine the exact status of the suggestion made here. It may seem presumptuous on the part of the writer to present his view, but he hopes that a discussion from a different angle will not be taken amiss.

PREVALENT VIEWS AS TO ORIGIN.

The splendid report of Jukes-Browne and Hill on the Cretaceous Chalk presents not only their own view as to the origin but also that of many others. A greater controversy developed over the question of the depth at which the Chalk was deposited (a perfectly natural question when the attempt is made to correlate the origin of the Chalk with that of the foraminiferal oozes) than over the source of its materials. The above authors[1] give the following as their view of the origin. "To sum up, therefore, we believe that the White Chalk of England and France is a deep-sea foraminiferal deposit comparable with the Biloculina ooze and with the lower layers of Globigerina ooze, but not identical with either. We believe that the disintegration of the organisms which have furnished the material of the calcareous matrix was accomplished beneath the floor of the Cretaceous sea, and that several kinds of organisms have contributed to its formation, one predominating at one time and one at another. Among these, spheres and shell-fragments are frequently as numerous as the tests of Foraminifera."

Jones, Hume, Geikie, and many other writers hold the same view as to the origin of the Chalk, although they differ as to the depth of the water in which it was formed, some favouring depths down to 1,000 fathoms or even greater (but still less than the depths at which Globigerina oozes are found, i.e. 2,400 fathoms), and others favouring a shallow depth, sometimes less than 100 fathoms. The writer believes it was laid down in a sea less than 400–500 fathoms deep and probably much less. There is no reason why much of it should not have been deposited in water less than 20 fathoms deep, although in some parts the fauna indicates a greater depth.

American geologists also favour an organic origin for the chalk of both the American and European deposits, believing that both plants and animals have contributed to its make-up. They, on the whole, favour a shallow water origin.

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[1] Jukes-Browne and Hill, *The Cretaceous of Britain*, vol. ii, 1903, p. 540.

THE COMPOSITION OF THE CHALK.

The Chalk is too well known by all geologists to make it necessary to give a detailed description of it. It is divided into three major divisions and each of these in turn into further subdivisions, both faunal and lithological evidence being used for this purpose. These divisions are as follow :—

	ZONES.
Upper Chalk = Senonian	*Ostrea lunata.*
	Belemnitella mucronata.
	Actinocamax quadratus.
	Marsupites testudinarius.
	Micraster coranguinum.
	,, *cortestudinarium.*
	Holaster planus.
Middle Chalk = Turonian	*Terebratulina.*
	Rhynchonella cuvieri.
Lower Chalk = Cenomanian	*Holaster subglobosus.*
	Ammonites varians.

The Chalk is also subdivided on a basis of colour and as to whether it is flintless or not. In this discussion the simple terms, Lower, Middle, and Upper, will be used in referring to the subdivisions.

The details of the composition of the Chalk as given by Jukes-Browne and Hill (who made the microscopic examination) in their report on the Cretaceous Rocks of Britain are the best available, and are the source of the information regarding the Chalk in this paper. In general three types of material (aside from the flints, the origin of which is a special problem) compose the Chalk, (1) organic remains, (2) so-called amorphous material (the spheres and possibly " cells " should be in this group, as will be seen later), and (3) inorganic materials, clay, sand, glauconite, and other detrital materials.

(*a*) *Organic Materials.*—The organic remains of the Chalk are shells, tests, and fragments of various mollusca and echinodermata, foraminifera, radiolaria, sponge spicules, and many other forms; all largely calcareous save the radiolaria and sponges, which are mainly siliceous. Fragments, especially prismatic rods, of Inoceramus shells, are abundant in the Lower Chalk and lower part of the Middle Chalk, but decrease in amount upwards. These rods appear to break down into small angular grains (called calcite) and often comprise a large percentage of the rock. Locally, shell fragments exceed all other constituents. Sorting by currents has helped in this concentration of coarse materials. Complete fossils are, of course, fairly common in many parts of the Chalk. All hollow forms are usually filled with the fine chalky material.

The foraminifera vary in amount in different parts of the Chalk, but on the whole are more abundant in the Lower Chalk (though they do not predominate) than in the Middle and Upper Chalk.

Hill (vol. ii, p. 534) states that "The proportion of foraminifera in the Middle and Upper Chalk is always small and that, though there are some horizons and localities where they are more abundant than usual, the average proportion is not more than 10 per cent of the mass, and is often only about 5 per cent (excluding spheres)".

(*b*) *Spheres and Cells.*—A very important phase of the problem is the origin of the spheres. These are small bodies either perfectly spherical or slightly ovoid in outline. Hill states that they "appear to be simple monothalamous cells, with comparatively stout walls, the material of which is now finely granular, crystalline calcite. In both varieties (spherical and ovoid) the centre of the cell, though often hollow, is frequently filled with minute calcitic crystals. In size, the spheres are usually from ·06 to ·08 mm. in diameter, a few of the largest reaching ·1 mm., rarely more. The ovoid forms are rather smaller than the average sized sphere" (vol. ii, p. 500). Elsewhere, also, the spheres in the Lower Chalk are stated to be mainly less than ·01 mm. in diameter. On another page (328) he states that "They are all filled with amorphous (sometimes crystalline) material". Many have calcite crystals adhering to their surfaces.

Are these spheres of organic or inorganic origin? Hill makes some statements regarding this. The minutely rounded bodies have been variously determined to be coccoliths, rhabdospheres, or foraminifera. As to the first two, Hill quotes Murray and Blackman, who hold that most of the bodies assigned to this group by geologists "have no claim to be so considered". And furthermore that "There is no evidence that they are derived from even allied organisms". From his own studies Hill apparently agrees with this conclusion, and in a later paper states, "we have not been able to identify a coccolith. Rhabdospheres may be frequently seen." No further reference is made to these two forms.

As to their being the young of foraminifera, Hill says (p. 500) since there are thousands of them present in the Chalk, we should be able "to follow the sphere to its adult stage". But "no such progress can be seen towards the fully developed Globigerina or any other foraminifera and, whatever their real nature may be, they certainly appear to have reached maturity". After citing the views of various other authors as to their origin, Hill (p. 501) closes his remarks with the following: "but the real nature of the majority of these calcareous spheres still remains an enigma."

Later, however, vol. ii, p. 523, Hill, in summing up the composition of the Middle Chalk, makes some statements, of which the following is typical, showing that apparently he still regarded the spheres as organic. He states that some specimens of the Lower Middle Chalk (*Rhynchonella cuvieri* zone) contain 70 to 80 per cent of spheres. "These *organisms*,[1] though often locally abundant in the Lower Chalk, are never so constant a feature as at this horizon."

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[1] Italics by W. A. T.

Small " cells " are frequently mentioned as constituting a part of the Chalk, and many of these are thought by Hill to be " without doubt the young of foraminifera ". The walls of the cells are thinner and they are more irregular in outline than the spheres. They are easily recognized in the Upper Chalk where spheres are less common.

In the light of Vaughan's studies of the calcareous mud flats of the Bahamas and Florida Keys, these spheres (and possibly some of the cells) appear to be explained far more satisfactorily as oolites, as will be shown below.

(*c*) *The Amorphous Calcareous Material.*—The larger part of the Chalk consists of material so fine that its nature is essentially indeterminate by the microscope, and because of this it is generally called " amorphous " calcareous material. The term is, however, very inapt as applied to calcareous material, as Johnston, Merwin, and Williamson [1] have shown that all forms of $CaCO_3$ are crystalline and never " amorphous ", i.e. non-crystalline, in the usual sense of the word. The crystalline material may be so extremely fine-grained as to be unresolvable by the microscope, and thus appears amorphous.

The outstanding feature of the Chalk is the amount of this extremely fine material that it contains. The quantity varies in different localities, but in a general way it may be said that it is more abundant in the Chalk of the east of England and in the north central part of France.

Some parts of the Chalk of the south of England, however, contain as much fine grained or dense material as that in Norfolk or Lincolnshire.

The rough table on p. 257 compiled from Hill's statements (Hill used Hume's material also) will give a very good idea as to the abundance of this dense or amorphous material. In the main these statements are as to the amount of " amorphous " material, and do not include spheres or cells.

That the Chalk is dominantly composed of this dense or amorphous material is evident from the above table. There are local variations, yet the big feature is the presence of this very dense material that acts as a matrix for the fossils and spheres and fills them if they are hollow. The same general features hold true for the Chalk of France and Belgium.

Composition of the Amorphous Material.—Strictly speaking, the amorphous material should show no definite structure. Hill, however, attempted by washing to get at its mechanical composition. The material is essentially all calcium carbonate, the insoluble residue consisting of clay and bits of detrital minerals, and, except locally or in the case of the *marly beds*, rarely exceeding one or two per cent. It consists of (1) calcitic grains, evidently parts of shells

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[1] Johnston, Merwin, and Williamson, " The Several Forms of Calcium Carbonate ": *Am. Journ. Sc.*, xli, 1916, 473.

	ZONE.	CHARACTER OF ZONE.
UPPER CHALK	*Ostrea lunata*	50% “ amorphous ” material.
	Belemnitella mucronata	70–90% “ amorphous ” material, remainder spheres and organic remains.
	Actinocamax quadratus	80–85% “ amorphous ” material, remainder spheres and organic remains.
	Marsupites testudinarius	70–80% “ amorphous ” material, spheres, and organic remains, 2% or less.
	Micraster coranguinum	Mainly “ amorphous ” material. Recognizable parts rarely exceed 25%.
	Micraster cortestudinarium	“ Amorphous ” material 20–70%. Organic remains more abundant in south of England.
	Holaster planus	In south and south-west of England, “ amorphous ” material less than 50%. Norfolk, Lincoln, and York, 80–85% “ amorphous ”.
MIDDLE CHALK	*Terebratulina*	Top ⅓, Spheres and organic material increase, but “ amorphous ” matter greatly predominates. Middle, almost exclusively “ amorphous ” material. Lower ⅓, Spheres decrease and “ amorphous ” material increases, both greatly predominate over organic remains.
	Rhynchonella cuvieri	Almost entirely spheres—50–80%—and “ amorphous ” material. In Devon, Beer Freestone has abundant organic remains. Foraminifera few.
	Melbourn Rock	Chiefly spheres and “ amorphous ” matter. Only locally do organisms exceed 50%.
LOWER CHALK	Belemnitella Marls	Some portions high in “ amorphous ” material, other in organic remains.
	Holaster subglobosus	40–90% “ amorphous ” material in south and south-west of England. 85–90% “ amorphous ” material in Norfolk, Lincoln, and York.
	Totternhoe Stone	60–70% of rock is composed of fragments of Inoceramus shells, matrix is amorphous.
	Ammonites varians	Dominantly organic in south and south-west of England, “ Amorphous ” matter = 25 to 50%, 60–80% “ amorphous ” in north of England.
	Chloritic Marls	Locally very rich in “ amorphous ” matter.

and tests, (2) crystalloids and similar forms (whatever these may mean), (3) " minute calcitic crystals, giving no clue to their derivation ", and (4) unresolvable materials.

There is no doubt that minute particles of tests and shells are present in this fine material. Doubtless, also, some of the material designated as " crystalloids " by Hill may be due to recrystallization since the deposition of the Chalk. The calcareous oozes of the Bahamas and Florida Keys, contain needles of aragonite, but these " crystalloids " do not appear to have had a needle shape, for otherwise Hill would certainly have mentioned it. It is also unlikely that aragonite needles would have persisted to the present time as they would have become calcite. It may be possible that the crystalloids represent their former presence, although it seems much more probable that the third group of " calcitic crystals " would represent such former aragonite needles, if any were ever present. The last group of extremely fine materials, if carefully washed and examined with the highest powers of a microscope or ultra-microscope, would probably be found to be minutely crystalline.

CHEMICAL COMPOSITION OF THE CHALK.

The Chalk is a remarkably pure calcareous rock. Certain beds, especially in the south-west of England and north-west of France, contain considerable detrital material, but in the north, east, and south-east of England and northern France it is very pure. The lower part of the Lower Chalk is the most impure. Above the Totternhoe Stone it contains from 88 to 94 per cent of $CaCO_3$, averaging about 89 to 90 per cent. It is purest from Norfolk northwards. The Middle Chalk is very pure. The Beer Stone in Devonshire, composed mainly of organic remains, contains the least $CaCO_3$, 93·38 per cent, all other parts of the Rhynchonella zone contain from 95 to 98 per cent $CaCO_3$. The Terebratulina zone, " never contains less than 96 per cent of carbonates and sometimes has as much as 99 per cent." The Upper Chalk is on the average even purer than the Middle Chalk, showing from 97·5 to 99 per cent of $CaCO_3$. The total amount of carbonates never falls below 95 per cent.

The flint and chert in the Chalk are not included in these analyses. On the whole the Chalk of the Anglo-French basin is a remarkably pure calcareous deposit. This purity is favourable evidence of its chemical origin, as will be seen below.

THE POSSIBLE CHEMICAL ORIGIN OF THE CHALK.

The evidence for a possible chemical origin of the Chalk will now be considered.

1. The organic remains do not show marked evidence of attrition, on the contrary they are well preserved. This feature is opposed to any view that seeks to explain the dense material as

finely ground organic remains. Furthermore, it is markedly lacking in evidences of strong current action. Locally there had been, evidently, a very slight sorting by such action, but that is all. Another point is worth noting. Some portions of the beds contain abundant prismatic rods of Inoceramus shells, which are not the result of mechanical breaking up of the shells, but of disintegration through the decay of the organic binding material.

2. The massiveness of the Chalk and the marked absence of stratification indicate a lack of marked agitation of the water in which it was deposited. The lines of flints are the only means of determining the structure in some places.

3. It is not possible to conceive of attrition producing the dense fine-grained material of the matrix without it also having destroyed the thin-walled spheres and cells, which are, on the contrary, well preserved in all parts. The spheres and cells were buried in a fine-grained material which was produced without agitation of the water.

4. Most of the recognizable materials composing the Chalk have not been proved to be of organic origin by those who have studied it, and these portions are, moreover, distinctly subordinate in amount to the amorphous matrix and spheres, save for some local exceptions. The number of these exceptions are so few as to make the scarcity of organic remains a remarkable feature, for one would expect more of them.

The lack of mechanical wear; the evident absence of currents, as shown by massiveness and lack of stratification; the perfectly preserved minute spheres and cells; and the absolute lack of any evidence of an organic origin of the dense material, all favour the view that the Chalk was inorganic in origin.

The writer suggests that the dense material constituting the dominant part of the Chalk is mainly of chemical origin, that it represents a precipitate of calcium carbonate from a saturated sea-water, and that the organic remains are analagous to such remains in a shale or a sandstone. Likewise, the lack of any real evidence of the organic origin of the spheres (other than that they are round like foraminifera) favours the view that they are really minute oolites, like those proven by Vaughan[1] to be forming in the calcareous oozes of the Bahamas and the Florida Keys. These range in size from ·004 to ·8 mm. in diameter, and consist of from one to four or five layers formed about a nucleus, such as a bit of calcite, shell, quartz or bubble of gas. Those formed about gas are hollow. The smaller of these oolites have one thin wall, like the spheres and cells. These spherulites or oolites are chemical precipitates and form wherever conditions are favourable for their development. Oolites up to ·23 mm. in diameter developed in samples of these muds after being taken to the laboratory. The

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[1] T. W. Vaughan, *Jour. Wash. Acad. Sci.*, iii, 1913, 303. T. W. Vaughan, Pub. 213 Carnegie Inst. of Washington, vol. ix, p. 266, etc.

Bahamas are built up almost entirely of an oolitic limestone, evidently formed as a chemical deposit. Oolites are forming as chemical precipitates at present also in Great Salt Lake, Utah.

The finest materials in the Chalk probably represent the calcium carbonate thrown down from the saturated surface layer. This material in the Bahamas and Florida Keys consists of "aragonite needles and particles so minute as to be visible only with a very high power microscope or the ultra-microscope". These needles are very abundant on the Bahama Banks. Minute calcite rhombs occur in the muds on the Florida Keys. Much colloidal material is present in these calcareous muds, and one sample from the Florida Keys contained 69·8 per cent clay-sized particles (less than ·005 mm.). Vaughan states the presence of the aragonite needles shows the materials to be chemical precipitates.

The similarity between the Chalk and the materials of the Bahama Bank is remarkable. Both contain organic remains: various mollusca, a few foraminifera and other forms, and spheres or oolites, in a matrix of extremely fine material. However, the writer does not wish to say that the conditions during the formation of the Chalk were identical with those of the present-day deposits, yet they may have been quite similar, and would therefore favour the possible chemical origin.

The high calcium carbonate content, above 95 per cent, of most of the Chalk and especially of the Middle and Upper Chalk is favourable to the view that it is a shallow or moderately deep-water deposit. Vaughan, after many years of study of shallow water deposits, says[1] "that a limestone of a high degree of purity, that is, from 95 to over 99 per cent $CaCO_3$, is usually either a very shallow water or a moderately deep-water deposit. The purest limestone is a very shallow water deposit".

CAUSE OF PRECIPITATION.

Much work has been done in the last few years upon the problem of the precipitation of $CaCO_3$ in sea-water. One of the most important papers on the subject, because of the large amount of experimental work upon which it is based, is that of Johnston, Williamson, and Merwin, of the Geophysical Laboratory of Washington, on the various forms of $CaCO_3$.[2] A later paper gives the application of their results to geology.[3] They show that, aside from direct evaporation of water and the removal of $CaCO_3$ by organisms, the most important causes of precipitation are changes of temperature and of the concentration of CO_2 in the solution and the air in contact with it, as these two factors control the amount of $CaCO_3$ in a natural water. The loss of CO_2 means precipitation of $CaCO_3$ from a saturated solution. The loss of CO_2 may be due to " a diminished proportion of CO_2 in the air, or a higher temperature or both ; or it may be organisms which make use of the CO_2 in their vital processes, or the production by bacterial action of ammonia, which indirectly achieves the same result ; or, in short, it may be in any way in which the concentration of CO_2 may possibly be diminished. Consequently, if the surface layers of the sea are saturated, as we believe they are, precipitation of $CaCO_3$ will be brought about wherever any of the foregoing agencies are operating " (Johnston and Williamson, *Journ. Geol.*, xxiv, 1916, 739).

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[1] T. W. Vaughan, ibid.

[2] Johnston, Williamson, and Merwin, "The Several Forms of $CaCO_3$": *Am. Jour. Sc.*, xli, 1916, 473.

[3] Johnston and Williamson, "The Rôle of Inorganic Agencies in the Deposition of Calcium Carbonate": *Jour. Geol.*, xxiv, 1916, 729.

These authors on a previous page (ibid. 734) state that " Consideration of the published analyses from this standpoint leads to the conclusion that the surface layers of the warmer parts of the sea (in so far as they have been investigated), as well as many river waters, are substantially saturated with calcite ". Supersaturation does not occur because calcite nuclei are always present, hence change in the conditions mentioned above means precipitation.

Cold water can absorb and hold more CO_2 from the air than warm water. Thus the ocean water in the polar regions absorbs CO_2 from the air and sinking to the depths holds it and also receives some from the decay of organisms. As a result of this higher CO_2 content and lower temperature, $CaCO_3$ goes into solution in the deeper, cold waters, a fact shown by the solution of shells and tests in the depths.

Quoting Johnston and Williamson[1] again : " Now let us revert to the consequence of abstraction of CO_2, and consider what will happen when in the course of the oceanic circulation this cold water, which carries more CO_2 and more $CaCO_3$ than the warm surface layers, reaches the surface and is slowly warmed. In the first place it will gradually lose CO_2 to the air, the residual concentration of free CO_2 being dependent at any moment upon the temperature of the water and the proportion of CO_2 in the air at that place. The consequence of this loss is that the amount of calcium in solution will at some point exceed the concentration which the water is able to hold in solution—or, in other words, the product $[Ca^{++}]$ $[CO_2{}^{=}]$ reaches its characteristic precipitation value—whereupon precipitation sets in, and continues thereafter so long as the temperature continues to rise. This process is without doubt taking place now in tropical and subtropical regions wherever and whenever conditions are fulfilled."

Keeping in mind these very important statements as to the amount of $CaCO_3$ in the sea-water and the cause of its precipitation, let us examine the physical conditions of the Cretaceous sea in which the Chalk was deposited. This sea stretched from Central England eastward to South Russia. It had only a limited connexion with the Cretaceous sea of the Mediterranean, and probably also had a narrow connexion with the Atlantic. Of the two, the Atlantic connexion would be the most important, as it might permit the inflow of cold, calcium-bearing waters. This connexion is no more vital to this suggestion, however, than it is to the view that the Chalk is organic in origin, for the amount of $CaCO_3$ to be accounted for is the same for either view and no one has questioned the adequacy of the source. Furthermore, if the open ocean can supply sufficient $CaCO_3$ for such a deposit as exists at the Bahama Banks, which cover thousands of square miles, an interior sea or body of water would certainly be receiving ample $CaCO_3$ to bring it to the saturation point. Great Salt Lake, Utah, is another example that proves this point, since the streams of to-day are contributing the $CaCO_3$ now accumulating as oolites on the lake floor. All of the streams entering the lake contain notable quantities of $CaCO_3$, which are absent from the lake itself, thus proving that rapid precipitation takes place.

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[1] Ibid., pp. 741–2.

The land surrounding the Cretaceous sea was relatively low-lying, and from it only a small amount of clastic material was being contributed to the sea. As the amount of dissolved salts in streams from such areas is usually high, the sea was doubtless receiving more than a normal amount of calcium salts, and would soon become so saturated with $CaCO_3$, that its precipitation would take place.

The climate of the Cretaceous period is regarded by most, if not all, geologists as being mild and warm, or even tropical. Park[1] thinks that the Cretaceous seas of the Baltic zone were warm seas, such as are now found along the coast of West Africa and in Malaysia. Chamberlin and Salisbury[2] state that the climate was warm and mild as far north as Greenland and Spitsbergen. Thus the climatic conditions of the period, as well as the character of the Cretaceous sea, would meet the conditions specified by Johnston and Williamson as best adapted to the chemical precipitation of $CaCO_3$.

It can scarcely be argued that the source of $CaCO_3$ is inadequate, because *the Chalk was deposited* by some means; *therefore the supply of* $CaCO_3$ *was sufficient.* The real question is the relative importance of each of the contributing agents. With the physical and climatic factors favourable for producing a saturation of the surface layers of the Cretaceous seas chemical precipitation might and probably did proceed simultaneously with the accumulation of the remains of the fauna and flora of the period.

INFLUENCE OF BACTERIA ON PRECIPITATION.

The discovery of denitrifying bacteria by Drew[3] and the studies by Smith and Kellerman[4] showed that these forms were very abundant in the surface waters and also in the bottom muds of the sea and that the ammonia produced by them in their life processes might precipitate $CaCO_3$, thus:

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[1] James Park, *Text-book of Geology*, p. 415.

[2] Chamberlin and Salisbury, *Text-book of Geology*, vol. iii, p. 161.

[3] G. H. Drew, "On the Precipitation of $CaCO_3$ in the Sea by Marine Bacteria and on the Action of Denitrifying Bacteria in Tropical and Temperate Seas": Carnegie Inst. of Washington, Pub. 182, vol. v, 1914, 7–45.

[4] Smith and Kellerman, *Jour. Washington Acad. Sci.*, vol. iv, 1914, 400–2.

$$CaSO_4 + (NH_4)_2CO_3 = CaCO_3 + (NH_4)_2SO_4.$$

Later studies by Smith and Kellerman[1] proved that several other groups of bacteria, the vibrios (ammonifiers) especially, are able to bring about the same reaction even better than the denitrifying group. Vaughan,[2] after stating that the surface waters in many parts of the ocean are saturated with $CaCO_3$ and discussing its precipitation by chemical means, as indicated above, says: "therefore, theoretically there should be precipitation of $CaCO_3$ without any bacteria." He does not mean to imply that bacteria do not aid chemical precipitation but merely that it can proceed without their aid. Johnston and Williamson[3] state that undoubtedly organisms (bacteria) are a factor in precipitation if it is only in the sense of a catalysing agent. They suggest that the organisms are abundant where this precipitation is going on, because of the abundance of CO_2 available for their life processes. The chemical precipitation of $CaCO_3$ would set free this CO_2.

The direct precipitation of $CaCO_3$ has been proved to be a fact. The precipitated $CaCO_3$ takes the form of minute crystalline grains, aragonite needles and calcite, and rounded forms or oolites. The chalk consists dominantly of fine-grained material and spheres (oolites ?); the two greatly exceeding the amount of recognizable organic remains. Does not this suggest that the major part of the chalk is a chemical precipitate ?

SUMMARY.

The composition of chalk has been shown to consist dominantly of three types of material, in the order of their importance, (1) amorphous, or extremely fine-grained material, (2) spheres, and (3) organic remains.

The first, the writer believes, represents chemically precipitated calcite and aragonite, the second a chemically formed oolite, and the last the normal organic constituents.

Recent studies have shown that the surface waters of the ocean in favourable localities are saturated with $CaCO_3$ and that variations in amount of CO_2 mean either solution or precipitation. It is believed that the physical conditions of the Cretaceous sea favoured precipitation. Bacteria may have been a contributing factor.

It is hoped that the above suggestion of the possible chemical origin of a part of the chalk (the larger part) will cause those who have the opportunity of study to apply it further, for until the great amount of extremely fine material is accounted for the origin of chalk is not settled. The writer regards the chemical origin with favour because it seeks to explain the origin of chalk in the light of present knowledge of the precipitation of calcium carbonate from sea water.

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[1] Smith and Kellerman, "Oceanography in its Relation to other Earth Sciences": *Jour. Washington Acad. Sci.*, xiv, 1924, 323–5. Part of Vaughan's paper.

[2] T. W. Vaughan, ibid., p. 307.

[3] Ibid., p. 729.

The Coniston Limestone Series of the Kentmere District.

By G. H. Mitchell, B.Sc., University of Liverpool.

The paper by Dr. B. Smith, recently published in the Geological Magazine,[1] has drawn attention to the interesting relations of the Coniston Limestone Series in the Coniston District.

The present writer has been engaged in mapping and investigating the sequence farther east in the neighbourhood of Kentmere, and the evidence in this district lends support to certain of the views expressed in the previous paper. It may be of interest to add some notes on the Coniston Limestone Series here and to state the evidence bearing on its relation to the underlying Borrowdale Volcanic rocks. The junction in the Kentmere district is undoubtedly unconformable, as in the district farther west. Furthermore, the junction between the Stile End Beds and the overlying beds of the Coniston Limestone Series appears also to be unconformable. The rocks exposed in this district are the following :—

Silurian (Stockdale Shales).
Ashgill Shales.[2]
Interbedded limestones and shales of the Coniston Limestone Series.
Massive Limestone.
Unconformity.
Stockdale Rhyolite.
Stile End Beds (alternations of fine and coarse ash).
Conglomerate.
Unconformity.
Shap Rhyolite group of the Borrowdale Volcanic Series.

The Shap Rhyolitic rocks, as examined near the junction, consist in the main of pyroclastic material. They include lithic and crystal-lithic tuffs with some thin rhyolite bands. One trachytic flow was observed.

The relations of the sedimentary rocks of Ordovician age to the Borrowdale Volcanic rocks in this district appear worthy of note. Not only do the Stile End Beds rest with noticeable unconformity on the volcanic rocks, but the interbedded limestones and shales transgress the Stockdale Rhyolite and the underlying ashy beds and come to rest on the Borrowdale Volcanic Series.

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[1] B. Smith, "The Unconformable Base of the Coniston Limestone Series": Geol. Mag., Vol. LXI, 1924, pp. 163–7.

[2] In this paper the term Ashgill Shales is used in the old sense to include all the Ashgillian.

The basal conglomerate of the Coniston Limestone Series occurs on the slopes of Garbourn Pass and also at Great Howe, Sadghyll, in the valley of Long Sleddale, where it was noted by Mr. J. F. N. Green.[1] It consists of pebbles of volcanic material set in an ashy matrix and would appear, without doubt, to have been derived from the Borrowdale Volcanic rocks. Between these points, however, no outcrop of the conglomerate occurs. Its place is possibly taken by the coarse ashes which occur at the base of the thick series of ashes and ashy sandstones. The latter rest unconformably on the volcanic rocks at Stile End, and were given the name of Stile End Grassing Beds by Harkness and Nicholson. They consist of interbedded fine and coarse ashes, the coarse ashes predominating at the base and the finer deposits in the upper beds. The coarse ashes near the base are somewhat difficult to distinguish from true volcanic ashes. They are, however, almost always stratified. The finer ashy sandstones near the top of the formation have been worked for slates. Fossils are more common in the finer-grained rocks, but are badly preserved. The thickness of this division is about 250 feet, but the beds thin rather rapidly to the east and west of Stile End and are only seen in a very thin band in a few exposures on Garbourn Pass.

The Stockdale Rhyolite represents a local volcanic phase, and forms a somewhat lens-shaped mass with a maximum thickness of about 450 feet near Stile End Pass. (See Map, Fig. 1.) Before Stile End Farm is reached towards the west, the rhyolite has thinned out altogether. In view of the fact that the Stile End Beds are being overlapped westwards by the upper beds of the Coniston Limestone Series, the thinning of the rhyolite is attributed to the same cause. There may, however, have been variation in thickness in the original flow.

A massive limestone occurs at the base of the interbedded limestones and shales. It may be recognized in Hall Gill (behind Kentmere Hall) and in the bed of the River Kent near Force Jumb. At Kentmere Hall it does not exceed 20 feet in thickness, but appears to be rather thicker in the Kent River section. The massive limestone is succeeded by the thin-bedded limestones with shale partings which thin and thicken noticeably in short distances. The limestones are frequently rather nodular or concretionary and the shales are highly cleaved. No identifiable fossils have yet been found. For a considerable distance along Hall Gill these rocks rest directly on the Volcanic rocks of the Borrowdale Series. They pass upwards into the blue-grey Ashgill Shales which are highly fossiliferous. Many of the fossils recorded previously have been found, including *Staurocephalus*, which was found about 50 yards south of the road, slightly on the Troutbeck side of

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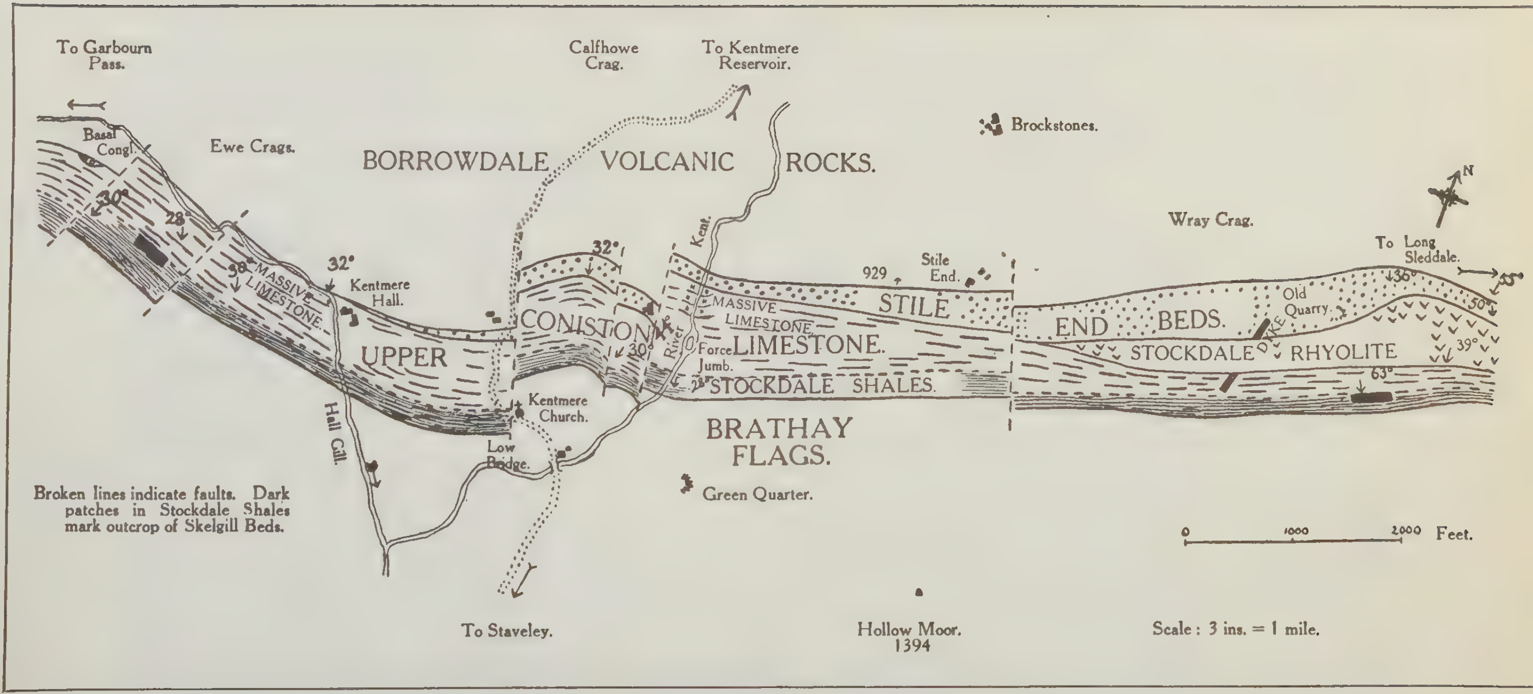
[1] J. F. N. Green, " The Structure of the Eastern part of the Lake District " : *Proc. Geol. Assoc.*, vol. xxvi, 1915, pp. 195–223.



Broken lines indicate faults. Dark patches in Stockdale Shales mark outcrop of Skelgill Beds.

FIG. 1.—The Coniston Limestone Series of the Kentmere District. The dip of 44° at Force Jumb is in the direction S. 14° E.

Garbourn Summit.[1] These shales mark the top of the Ordovician succession.

The interbedded limestones and shales, together with the Ashgill Shales, reach a considerable thickness (perhaps 400 feet) on the eastern slopes of Garbourn, but vary somewhat, being only about 175 feet thick near Stile End. This variation, however, is not due to the overlap of the Stockdale Shales, which are here strike-faulted against the Ashgill Shales. The mapping of the district shows that the interbedded limestones and shales, as has been stated, actually overlap the Stockdale Rhyolite and Stile End sandstones and ashes and rest directly on the Borrowdale Volcanic rocks. At one point, some little distance below the summit of the Stile End Pass on the Long Sleddale side, the strike fault which normally bounds the Stockdale shales departs slightly from the junction, and a skin about 6 inches thick of Skelgill Beds may be seen resting on the Ashgillian. This strike fault probably also transgresses slightly into the Ashgill Shales at times.

The thickening and thinning of the upper rocks of the Coniston Limestone Series as exemplified in some of the sections, as well as in the main outcrop, together with the presence or absence of some of the divisions of the series, seem to point strongly to the conclusion that this group consists of a number of beds which vary in thickness independently. The frequent absence of fossils in an identifiable condition makes this difficult to prove conclusively. There is no trace of the ashy sandstone mentioned by Dr. B. Smith in the paper cited as overlying the Limestone in Torver Beck.

The Stockdale Shales present their usual characteristics, but in many cases the Skelgill division is cut out entirely or in part by the strike fault mentioned above.

The writer desires to express his gratitude to Professor J. E. Marr for many valuable hints in the preparation of this paper and to Professor P. G. H. Boswell for encouragement during the study of the district.

The Relation of the Edale Shales[2] to the Carboniferous Limestone in North Derbyshire.

By J. Wilfrid Jackson, M.Sc., F.G.S., Assistant Keeper of the Manchester Museum.

THE following paper deals with the results obtained from investigations made during recent years in North Derbyshire with a view towards elucidating the relation of the so-called " Yoredale " or " Pendleside " Series to the Carboniferous Limestone.

In a previous paper[3] I have given faunal reasons for concluding that the "shales with limestones" lying below the Kinder Scout Grit in Derbyshire, and frequently called by the names of "Yoredales" or "Pendlesides", should be included in the Millstone Grit Series, and consequently be regarded as Upper Carboniferous. To the lowest division of this Sub-Kinder Series I gave the name of Edale Shales, on account of their great development in the valley of the River Noe, at Edale. The black shales overlying the massif, referred to in this paper, belong to this lower division.

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[1] W. T. Aveline, " The Geology of the Country between Kendal, Sedbergh, Bowness, and Tebay " : *Mem. Geol. Surv.*, 1888, pp. 58 9. J. E. Marr, " The Ashgillian Succession West of Coniston Lake " : *Q.J.G.S.*, vol. lxxi, 1916, pp. 189–204.

[2] = the so-called " Yoredale " or " Pendleside " Series.

[3] J. W. Jackson, *The Naturalist*, October, 1923, pp. 337–8.

The relation of these Edale Shales to the limestone has always presented some difficulty in its interpretation, and in consequence numerous faults have been suggested to account for the irregular boundary between the two series seen in certain places in North Derbyshire and elsewhere.[1]

My own observations in the district have led me to the conclusion that the irregular boundary is largely due to unconformable relationship.

Unconformity between the Carboniferous Limestone and the overlying shales has already been demonstrated on the eastern side of the massif by Principal T. F. Sibly and by Mr. C. B. Wedd.

In 1908,[2] the first-named authority described an interesting section seen in a quarry near Old Mill, beside the Bakewell and Winster road, east of Youlgreave. The black shales of the Pendleside Series, containing *Posidoniella laevis*, were there seen to rest with unconformity upon a surface formed by the truncated edges of limestone-beds representing a high level in the *Lonsdalia* subzone (D_2). This section was regarded by Principal Sibly as affording evidence of local earth-movement and erosion, contemporaneous with the deposition, in other parts of the area, of the uppermost beds of the Carboniferous Limestone or the lowest beds of the Pendleside Series. It was suggested that the absence of the *Cyathaxonia* beds may be due, either to their removal by denudation during early Pendleside time, or to the locality having formed land during *Cyathaxonia* time.

A somewhat similar example of local unconformity at Darleybridge, a few miles distant from the above-mentioned section, is described by Mr. C. B. Wedd in his discussion of Principal Sibly's paper, and in the Geological Survey Memoir for 1913.[3] The Darley section showed an anticlinal dome of limestone (in the *Lonsdalia*-subzone) dissected by quarrying operations. If stripped of the shale the dome would have a knoll-like aspect. On the north and east sides these shales, nearly horizontal, overstepped the denuded edges of the cherty limestones (there normally about 50 feet thick) on to the white limestone below.

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[1] "The Geology of North Derbyshire": *Mem. Geol. Surv.*, 2nd ed., 1887, pp. 33, etc.

[2] T. F. Sibly, *Q.J.G.S.*, vol. lxiv, 1908, pp. 63–4, fig. 5.

[3] C. B. Wedd, *Q.J.G.S.*, vol. lxiv, 1908, p. 81, and "The Geology of the Northern Part of Derby Coalfield, etc.": *Mem. Geol. Surv.*, 1913, p. 35.

In 1897,[1] Messrs. Barnes and Holroyd described a section above the Odin Fissure, Treak Cliff, Castleton, where the "Yoredale" Shales were seen resting unconformably upon a very irregular and worn surface of limestone. And still earlier, Mr. John Taylor, Jr.,[2] described a brook section below Mam Tor, Castleton, where "Yoredale" Shales were observed abutting against the lower limestones. This observer states: "These shales are intercalated with bands of gritstone, which appear to be charged with the fragments of comminuted shells and Encrinite stems, the remains of the old beds, which had been denuded away, but they do not contain any fossils of their own."

The chief area of my researches has been along the northern boundary of the limestone massif, between Doveholes on the west and Bradwell on the east.

The railway-cutting to the Peak Forest limestone quarries, about half a mile north of Doveholes, shows the junction between the massif and the shales. The section here was described in 1901 by Dr. Wheelton Hind,[3] but no fossils were noted. It was examined in later years by Mr. Henry Day (a former research student at Manchester University) and myself. The beds of the massif consist of grey, chertless, crinoidal limestones, with numerous fossils, dipping west by north at 15°. The age of these beds is uncertain, but they are probably not more than about 350–400 feet above the Lower Lava of Doveholes Dale, and if this estimate is correct their position would be in the lower half of the *Lonsdalia*-subzone (D_2) of Sibly's[4] classification. Overlying the limestones are some 20 feet of black shales and thin black limestones with an apparent dip of 12° in a direction N. 30° W. They are now much overgrown with vegetation. The shales at the junction are somewhat crushed and slickensided, due probably to disturbance during post-Carboniferous folding. Fossils are scarce, but *Posidoniella cf. laevis* was seen at 10 inches and 2 feet up in the sequence. At a slightly higher level the shales contained occasional specimens of *Pterinopecten* sp. and *Pseudamusium* sp. in fair abundance. Fragments of crinoid stems were also fairly frequent, but no goniatites were noted.

In the narrow Bolt Edge Valley, from the Clough Inn to Sparrowpit, further north, though the limestone-shale boundary can be easily traced, actual exposures of the junction are scarce. Near the Clough Inn the boundary lies to the south of the main road, but just before reaching the Ebbing and Flowing Well it crosses to the northern side and occupies the bottom of the valley to Sparrowpit. Opposite B.M. 1016·1 (6 in. map), about 180 yards east of Clough Inn, is a series resting on the massif of black limestone bands and black carbonaceous shales with a conglomeratic band. The conglomerate consists of small phosphatic nodules,[1] and the black shales contain comminuted shell-debris made up of *Chonetes* (small species), a ribbed rhynchonellid, and crinoid ossicles and columnals. Abundant scales of silvery mica occur in some of the shales.

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[1] *Trans. Manch. Geol. Soc.*, vol. xxv, 1897, pp. 125, 129.
[2] Ibid., vol. iii, 1861, pp. 76–7.
[3] *Q.J.G.S.*, vol. lvii, 1901, pp. 368–9, 377.
[4] *Q.J.G.S.*, vol. lxiv, 1908, p. 39, fig. 2.

The limestone of the massif is exposed at several places on the dip-slope of Barmoor, the general strike being approximately S.W.–N.E., swinging round to S.S.W.–N.N.E., towards Sparrowpit. The dips are low and vary from 10°–30°. The limestones are mainly of the massive crinoidal type (well seen in the large Barmoor quarry, celebrated for its numerous palatal teeth of fishes),[2] but cherty limestones are present at the old quarry south of Sparrowpit. At Bolt Edge Farm, opposite Barmoor quarry, the shales apparently rest on the edges of limestones dipping in the opposite direction, i.e. S.E. instead of N.W. The limestones of this valley are probably higher than those of the Doveholes cutting.

From Sparrowpit to Mam Tor, near Castleton, the shales occupy the floor of the large, wide, flat-bottomed Rushup Edge Valley, but only a few rather unsatisfactory exposures are seen of the limestone-shale junction, owing to the presence of a thick deposit of what appear to be ancient river-gravels composed of grits and sandstones. The boundary, however, can be traced with fair accuracy by the dominant rush vegetation on the shales, and by the line of swallow-holes which take the water of the small streams from Rushup Edge.

Between Sparrowpit and Perryfoot the ground is disturbed by faulting and mineral-veins, but at Tortop, near Perryfoot, a series of black shales and limestones is seen dipping N.W. off massive limestones with crinoids and other fossils. These limestones resemble those seen in the Doveholes cutting, and, in part, those of the Bolt Edge Valley. Higher in the shales are thinly-bedded black limestones containing crinoid-stems, goniatites (especially *Eumorphoceras bisulcatum*), nautiloids, etc. These are probably not more than 75 feet above the junction.

From Perryfoot to Middle Hill and Peakshill, the junction is marked by swallow-holes, and at a few places along this line the small streams from Rushup Edge have cut down through the gravels and exposed sections of black shales with bands of hard, black mudstones, dipping north-westerly at 15°–20°. The actual junction, however, is not exposed. The limestone is seen at several places near the junction and consists of massive, chertless beds, with numerous fossils.

South-east of Peakshill Farm, a fault ranging N.N.E.–S.S.W., breaks the continuity of the junction, and further east, between Giant's Hole and Windy Knoll, the shales form a salient into the limestone, which in this neighbourhood is of the "Brachiopod

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[1] For the identification of these nodules I am indebted to Mr. G. Andrew, M.Sc., Assistant Lecturer in Geology, Victoria University.

[2] Geol. Mag., Vol. LVI, 1919, p. 62.

Bed " type, containing a few corals including typical *Cyathophyllum regium*. This latter would appear to date the horizon as the subzone of *Lonsdalia floriformis* ($=D_2$). The salient is probably quite normal and due to the shales following the folding in the limestone.

At Windy Knoll the junction appears to lie a little to the north of the Elaterite quarry. The fissures in this quarry contain a large amount of black shale, indicating unconformable overstep.

Between Treak Cliff (" Brachiopod Beds ") and Mam Tor the true relation of the shales to the limestone is obscured by faulting and landslides, but in certain places the shales can be seen resting upon an uneven surface of limestone.

From Treak Cliff eastwards through Castleton to Pin Dale, the boundary appears to be a natural one, but the shales are not seen along this section. The limestone is mainly of the massive type with numerous fossils and dips at 20–30° towards the boundary. At several places along this line the upper beds consist of a conglomerate of water-worn valves of *Productus* and other fossils—the so called " Beach Bed " of Messrs. Barnes and Holroyd.[1]

The irregular limestone boundary to the east of Pin Dale was thought by the officers of the Geological Survey in 1887 to be due to a succession of faults, but quarrying operations at Nun Low, immediately east of Pin Dale, have disproved this theory and revealed a most interesting and convincing instance of unconformable junction between the Carboniferous Limestone and the Shales.

The Nun Low quarry has been opened in massive chertless limestone in the form of a fold pitching approximately N.N.W. Some portions of the limestone are highly fossiliferous and contain typical examples of the brachiopods figured by W. Martin in his *Petrificata Derbiensia*, 1809, especially *Spirifer striatus*, *Pugnax acuminatus*, and *Productus semireticulatus*.

Two years ago indications of unconformity were noticed in a small exposure on the north-eastern side of the quarry. The cutting of a new trench through the shales to form a road into the quarry has recently exposed an interesting section showing definite transgression of the shales on to an irregular and channelled surface of limestone.[2] The black shales at the exposed junction are seen dipping at 55° N.E. off the denuded edges of highly fossiliferous limestones. Pockets and fissures in the limestone are also filled with shale. In certain places fragments of the thin, hard, basal-bed of the shales are still affixed to the surface of the eroded limestone, and the removal of these plates reveals several Carboniferous Limestone brachiopods, *Archaeocidaris* plates, etc., embedded in the matrix.

The limestones on this side of the quarry dip at 40° E., and some 60 ft. above the quarry floor and 35 feet above the exposed junction, is a bed of greenish tuff (nearly 3 feet thick), containing several fossils, more particularly *Goniatites crenistria.* This bed is succeeded by tufaceous limestones with numerous encrinite-stems, *Productus* spp., and other fossils, including the above-mentioned goniatite.

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[1] *Trans. Manch. Geol. Soc.*, vol. xxv, 1896, pp. 119–32.

[2] I am indebted to the owners, Messrs. John Hadfield & Sons, Ltd., of Sheffield, for permission to examine this interesting section and quarry.

The hillside is covered with a thick deposit of rainwash consisting of weathered limestone and tuff which extends down over the shales. The junction of the latter with the limestone is thus masked, and is only visible in the new trench.

Judging from the pitch of the fold, the junction between the shales and the tuff must have been exposed somewhat to the north when the quarry was first opened. The only evidence now available of the overstep of the shales on to this horizon is the presence on the nearby waste-heap of blocks of tuff with the basal plate of the shales still attached to them.

At the north-western end of the quarry face the unconformity is again seen. Here the black shales rest on the truncated edges of higher limestones than at the eastern end. These limestones are crowded with fossils, chiefly brachiopods, together with *G. crenistria*; they dip N.W. to the boundary at a low angle, but the shales are not sufficiently exposed at present for detailed examination. A much attenuated development of the tuff is seen some 60 feet down in the limestone, and disappears at the entrance to a small cave on a level with the quarry-floor. The total amount of overstep actually seen in the two exposures of the shale and limestone junction in this quarry is at least 100 feet.

The age of the Nun Low Limestones presents some difficulty owing to their being of the "Brachiopod Bed" type and thus wanting in the typical zone corals. The brachiopods are all high Avonian forms and such as are to be found in similar beds along the northern and western margins of the massif. They also agree in a remarkable manner with the fauna of the Cracoe knolls of the Craven area.

The Derbyshire "Brachiopod Beds" were regarded by Principal Sibly[1] as pertaining to the Middle *Dibunophyllum*-subzone ($=D_2$), possibly encroaching somewhat on the succeeding subzone D_3.

It is of some interest to notice the presence of *Goniatites crenistria* in the Nun Low Limestones. It occurs mainly in the beds overlying the tuff, and is by no means rare. This species is equally abundant in the Poolvash and Cracoe knolls, and, according to my own experience and that of Mr. W. S. Bisat and other workers, it does not occur below the upper part of the Pendleside Limestone, the fauna of which suggests D_3. Hence it would seem that this goniatite has a certain zonal value.

There are several other fossils in the *Crenistria*-beds at Nun Low which point equally to a high horizon, for example, *Solenocheilus* (=*Nautilus*) *ingens* (Martin) and *Actinoceras* (=*Orthoceras*) *breynii* (Martin), the types of which were described from the "Black

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[1] *Q.J.G.S.*, vol. lxiv, 1908, pp. 48–50.

Marble" of Ashford[1] (=D_3, *vide* Sibly). *Pinna flabelliformis* (Martin) is another Ashford type which occurs at Nun Low. I have also collected *Solenocheilus derbiensis* Foord at both Ashford and Nun Low.

The evidence at Nun Low of volcanic activity occurring in the uppermost Avonian is interesting in view of similar evidence at Tissington[2] and Congleton Edge.[3] At the first-named locality *Posidonomya becheri* occurred together with a typical assemblage of D_3 corals and brachiopods in a series of alternating tufaceous limestones and shales, about 100 feet thick, overlying the bedded tuff.[4]

Pending further detailed study, little can be said regarding the age of the shales which overstep the limestone at Nun Low. The beds exposed in the new trench are highly bituminous, smelling strongly when broken up. Several beds of decalcified "bullions" are present, the "bullions" retaining their shape, but their interiors are soft and crumbly. The only fossils so far obtained consist of indeterminate plants and fish remains, together with numerous specimens of *Posidonomya cf. membranacea* (large ovate form without radial markings), *Posidoniella* (small species), *Pseudamusium cf. praetenuis* (v. Koen.), and rather obscure fragments of a *Eumorphoceras* which may be either *pseudobilingue* Bisat or *bisulcatum* Girty.

Posidonomya membranacea is characteristic of the Upper Bowland Shales of Pendle (=*Pseudobilingue* zone), but appears somewhat earlier and also extends up into the basal beds of the Sabden Shales, judging from specimens which I have examined.

The *Pseudamusium* agrees with specimens figured by Wolterstorff, in 1899,[5] as *cf. praetenuis* v. Koenen, and I consider this form identical with the *Pseudamusium fibrillosum* Hind (non Salter).[6] The same form is common with *P. membranacea* in the *Pseudobilingue* beds near Linton Stepping Stones, north of the Craven Fault, and it is interesting to note that the Bowland Shales here evidently overlap the limestone massif.[7] The species also occurs in shales resting on the limestones at Bradwell, about a mile and a quarter to the south-east of Nun Low quarry, and is associated here with goniatites, including *Eumorphoceras bisulcatum*, a form characteristic of the Lower Sabden Shales.

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[1] *Petrificata Derbiensia*, 1809, pl. xli, fig. 5, and pl. xxxix, fig. 4, and App., p. 17.

[2] *Trans. N. Staff. Field Club*, xxxii (1897–8), pp. 114–16; *Q.J.G.S.*, vol. lv, 1899, pp. 224–38.

[3] *Q.J.G.S.*, vol. lv, 1899, pp. 548–59.

[4] *Q.J.G.S.*, vol. xliv, 1908, p. 59.

[5] *Jahrb. d. kgl. Preuss. geol. Landes.*, etc., for 1898 (1899), p. 47, pl. iii, figs. 8–16.

[6] *Monog. Brit. Carb. Lamell.* (*Pal. Soc.*), ii, 1903, p. 106, pl. xvi, figs. 20–2 (excl. figs. 16–19). *Pecten variabilis* M'Coy, Synopsis, 1844, p. 101, pl. xvi, fig. 7, has points of resemblance, judging from the illustration and description: this is referred (erroneously in my opinion) to the *Pseudamusium anisotum* (Phil.) by Hind.

[7] *Q.J.G.S.*, vol. lxxx, 1924, p. 248.

It is unfortunate that the Nun Low shales cannot be accurately dated at present, owing to the imperfection of the fauna. The presence at Bradwell and at Tortop, near Perryfoot, of shales with *Eu. bisulcatum* resting on the massif suggests that the shales at Nun Low may be of Lower Sabden Shale age. Even if they should represent the Upper Bowland Shales, they can only be an attenuated development of that series, as definite Upper Sabden Shale fossils occur at no great distance above.

I have already emphasized the important fact that the greater part, if not the whole, of the so-called " Yoredale " or " Pendleside " Series of Derbyshire (=Edale Shales. J. W. J.) is the homotaxial equivalent of the Sabden Shales of Lancashire and of the Todmorden Shales of Yorkshire.[1]

In a future paper I am presenting detailed evidence in justification of this correlation.

The correct determination of the fauna contained in the Edale Shales has had an important bearing upon the question of the age of certain beds ascribed to Kinder Scout Grit in Lancashire and Yorkshire. The evidence derived from the type area of Kinder Scout Grit has rendered it necessary to discard the term Kinder Grit in the case of the grit overlying the Pendle Grit and underlying the Sabden Shales. On the other hand it confirms the attribution of the name Kinder Grit to the grit overlying the shales in the Todmorden and Hebden Valleys.

Note on a Specimen of *Micraster* showing Unusual Features.

By NORMAN L. SILVESTER, M.Sc.

(PLATE X.)

THE specimen to be described was disinterred by the writer in a small and practically disused Chalk pit on the east side of the road leading from Sulham village (Berkshire) in a S.S.E. direction towards Theale, and 530 yards distant from the former. The place of burial was in the undisturbed face of the pit at about 5 feet above the road level of 190 feet above sea-level. The exposure is recorded on the 6 inch map sheet XXXVI surveyed by J. H. Blake in 1895. The Chalk in which the pit occurs is coloured as " Upper ", but the precise zone is not indicated either on the map or in the memoir (1).[2]

The external features of the test, with the exception of the arrangement of the pores of the paired ambulacra, correspond in all essentials with *M. coranguinum* Klein, as described in detail by T. Wright in his classical memoir (2).

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[1] *The Naturalist*, Oct., 1923, pp. 337–8.

[2] Figures in parentheses refer to the list of works given at the end of the paper.

A diagnosis based on the descriptions of A. W. Rowe (4) would (with the above exception) class the specimen as *M. coranguinum auctorum* var. *latior.* The general shape of the test is similar to his "*forma beonensis*". The anterior paired ambulacra are of the "sub-divided" type as illustrated in fig. 7, pl. 36 of his paper. This is one of his "high zonal" features by which he claims to be able to determine the horizon of a specimen. The zone indicated by this and other diagnostic criteria is that which bears the name of the species.

The dimensions of the test are :—

	mm.
Breadth . .	49
Length . .	48
Height . .	29

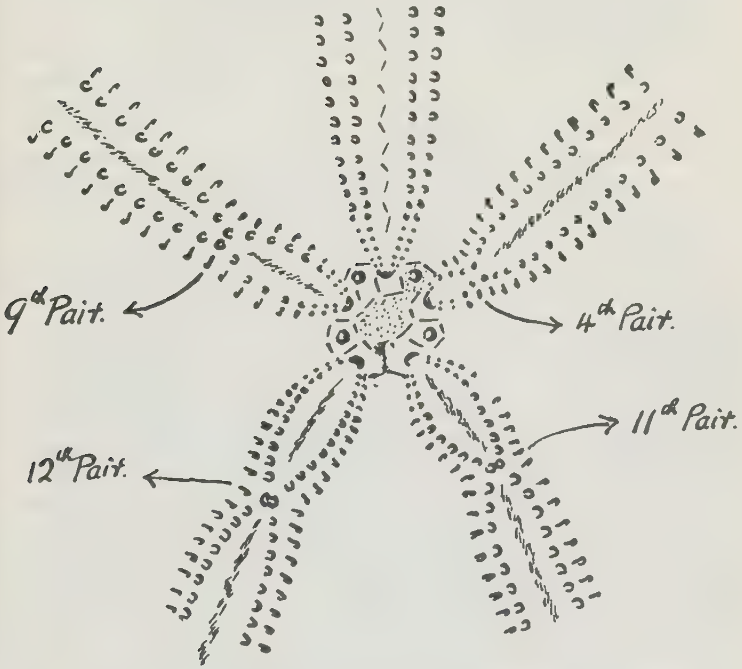

Diagram by N. L. Silvester.

FIG. 1.—Showing part of poriferous zone of ambulacra. × 4.
Micraster sp., Sulham, Berks.

A detailed description of the specimen is superfluous. It remains but to indicate in what manner it is dissimilar to the normal group. The diagram Fig. 1 is intended to illustrate this.

In the right anterior ambulacrum the pores at first diverge in the usual manner, but quickly converge again at the fourth pair from the apical disc. The result is a miniature petaloid structure close to the apical disc. After the fourth pair, a second divergence occurs, and the remainder of the poriferous zone is normal, i.e. sub-petaloid. In the left anterior ambulacrum the pores diverge and converge again at the ninth pair from the disc—so that the inner pores of the ninth pair approach to within 0·5 mm. of one another. A similar re-divergence occurs after the ninth pair. The right posterior ambulacrum shows a similar structure, but in this the convergence occurs at the eleventh pair and is emphasized because the inner pores now mutually impinge. In the left posterior ambulacrum the maximum convergence occurs at the twelfth pair with complete inosculation of the two inner pores. The convergence of the pores thus grows more complete as the distance of the convergence from the apical disc increases. The general appearance of the paired ambulacrum is seen to be " di-petaliferous " instead of sub-petaliferous as is usual in the species.

According to Wright (3), "the structure of the ambulacral areas and poriferous zones affords good characters of secondary importance for grouping the genera into natural families." If such importance is conceded to this di-petaliferous structure, it follows that this specimen must be removed, not only from the species but from its genus, into another hitherto unknown. In view, however, of its similarity in other respects to *M. coranguinum*, such drastic procedure would scarcely find justification.

Upon review of the number of species into which the genus of Micraster has been divided, and of the differences of opinion that have arisen amongst workers on this genus in the past, the writer has not the temerity to suggest a new specific name for this specimen. Might it be possible that it represents a type intermediate between Micraster and forms appearing in the Eocene such as Spatangus (Lam.), which are characterized by a more decided development of the petaloid structure of the ambulacra ?

Alternatively, it may be considered as an idiosyncrasy peculiar to this individual ; for, if the position of the pores be examined, in relation to the order of addition of new plates to the ambulacra during the growth of the test, one is led to the conclusion that the unusual features seen were due to a rejuvenescence of the urchin leading to a renewed secretion of plates at a late stage in the development of the test.

With a view to rendering the specimen more readily accessible to students of echinology, the writer proposes to deposit it with the Trustees of the British Museum (Natural History).

REFERENCES.

1. J. H. Blake, " Geology of Reading " : *Mem. Geol. Surv.*, 1903.
2. T. Wright, " Cretaceous Echinodermata " : *Monograph Palaeont. Soc.*, vol. i, 1864–82, pp. 270 et seqq., pl. lxii.
3. —— ibid., p. 29.

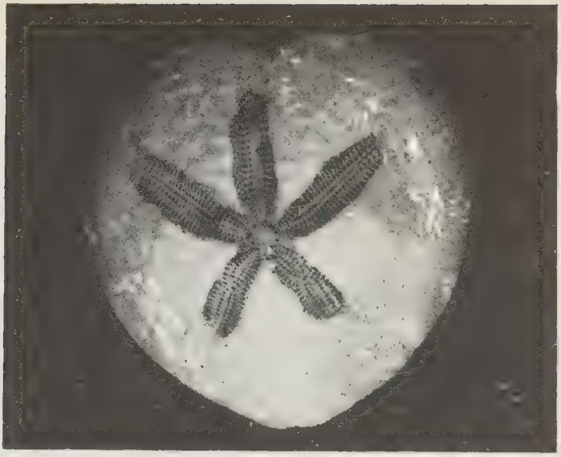

Photo by S. H. Morris.

MICRASTER SP., SULHAM, BERKS. Natural size (approx.).

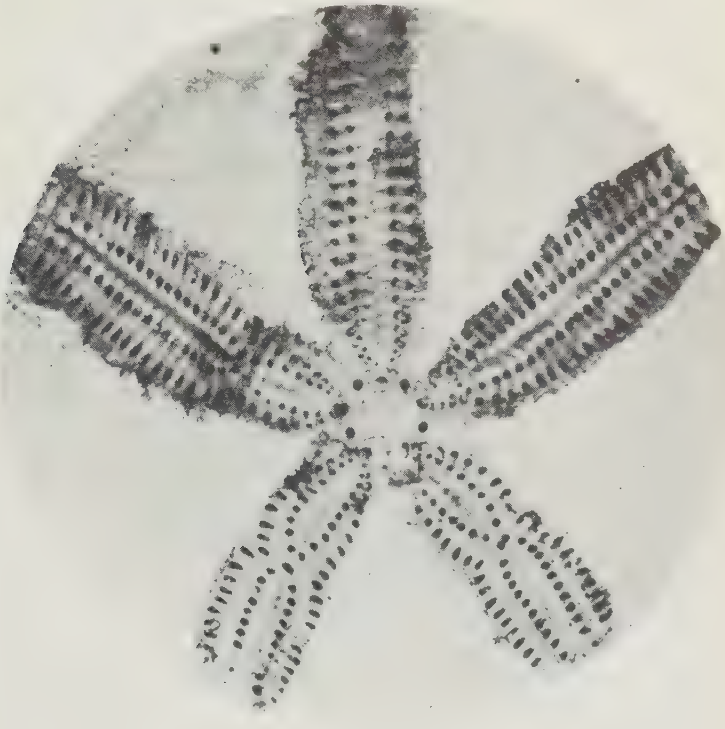

Photo by S. H. Morris.

MICRASTER SP., SULHAM, BERKS. Enlargement of above × 3·4 to show poriferous zone of ambulacral areas.

N.B.—The areas on the specimen were stained with sepia in order to enhance the definition of the pores.

[*To face p. 76.*

4. A. W. Rowe, *Q.J.G.S.*, vol. lv, 1899, p. 494 et seqq. (*vide* T. Wright, ibid., p. 271 et seqq., for bibliography prior to 1864; C. Evans, *Proc. Geol. Assoc.*, vol. v, 1877, p. 149; C. J. Mëyer, GEOL. MAG., 1878, p. 115; Dr. R. T. Jackson, *Monograph on Phylogeny of Echini. Boston Soc. Nat. Hist.*, 1912.

A Preliminary Note on the Glaciation of Borrowdale, Cumberland.

By A. RAISTRICK, M.Sc., F.G.S.

DURING an extended study of the glacial phenomena of the above area, which includes the drainage of the Rivers Derwent and Greta, and the drainage basin of Bassenthwaite Lake, several features of general interest were found which it is proposed to outline here.

The district is covered by rocks of two principal types, the Borrowdale Volcanic Series in the south and the Skiddaw Slate in the north. The hard rocks of the Borrowdale Series have preserved abundant ice scratches, while the softer Skiddaw Slates, though unable to retain the scratches, have kept the *moutonnée* form everywhere impressed upon them by the ice. Below an altitude varying from 1,250 feet O.D. in the north, to 2,000 feet O.D. in the south of the area, the striations and *roches moutonnées* are parallel with the valley sides, and the ice movement was almost entirely determined by the physical relief of the country. Above this level, the direction of both scratches and the *moutonnée* surfaces are generally constant in a N.N.W. direction, and they are the work of the upper portions of the ice at the time of maximum extent of the Cumberland ice-cap. The effects of the ice work are to be seen in the rounding of the mountain summits, the deepening and smoothing of the valleys, and in the slate area the emphasizing of the narrow ridges which separate the valleys.

The distribution of erratic boulders throws interesting light on the succession of events during the Ice Age in many parts of the area, but particularly in the Greta valley east of Keswick. In the Thirlmere valley the quartz-porphyry of the Armboth Dyke and the micro-granite of the Vale of St. John have provided ideal index erratics, while in the northern tributaries of the Greta, the Glenderaterra, and the Glenderamakin, the Skiddaw Granite and the metamorphosed representatives of the Skiddaw Slate have been equally useful. The Armboth Dyke erratics have travelled down Thirlmere (to the north) and divided on the High Rigg, a train of erratics passing down the valley on each side. The westerly stream by the Naddle valley deflects N.W. across Keswick and joins the north-west stream from Borrowdale. The erratics down the Vale of St. John, with the micro-granite, divide at the mouth of the Glenderaterra and travel in two directions. The erratics from the Skiddaw granite and the metamorphosed slates, coming from the north by the Glenderaterra valley also divide here and mingle with these two erratic trains, one of which goes eastward up the Greta valley to the Vale of Eden, and one goes to the west and north-west around the foot of Skiddaw, where after joining those from Thirlmere (by the Naddle valley) and from Borrowdale, the whole stream is deflected west across the Whinlatter and Lorton Fells. This deflection into the Lorton Vale was due to the presence of Scottish ice across the foot of the Bassenthwaite valley, preventing any northward passage of the Lake District ice.

During the period of ice retreat, several moraines and glacier lakes were formed, the most interesting being the moraines and lakes near Rosthwaite in Borrowdale, and the lake in Newlands Vale. At Rosthwaite, a triple concentric moraine closes the mouth of the Stonethwaite valley and its flank obstructs the Seathwaite valley to the south. The Derwent is deflected for some distance along the outside of the moraine, finally breaching part of it south of Longthwaite farm. Here the section shows an upper and lower clayey moraine, separated by a belt of clean sand about 2 ft. thick. The upper part of the moraine contains erratics from the igneous complex of Blea Crag in Langstrath, the upper part of the Stonethwaite valley, and these are entirely absent from the lower portion of the moraine. This lower portion contains many recognizable Styhead and Seathwaite rocks and no Blea Crag erratics. The upper and lower parts of the moraine were formed by ice from Stonethwaite Dale and Seathwaite Dale respectively, and other evidence can be adduced in support of this. The sands between the two clays are outwash sands from the Seathwaite ice. At the retreat of the ice, the Seathwaite branch of the Borrowdale glacier shrank more quickly than the Stonethwaite branch, for which the enormous Langstrath valley acted as an ice reservoir. The lower clay is the ground moraine of the Seathwaite ice, and the sands are largely the same material resorted by the melt-water of the retreating glacier. As the effect of the Langstrath reservoir was felt, a slight readvance of the retreating Stonethwaite ice was accompanied by a deploying of the foot of this glacier over ground previously covered by Seathwaite ice at the junction of the valleys. The retreat of the Stonethwaite ice was very slow, as the size of the moraine shows, and was marked by three periods of equilibrium, when ridges of additional moraine were deposited on top of the general moraine surface, which is about 40 feet above the valley floor.

This crescentic moraine held up a lake in the Seathwaite valley and in the Stonethwaite valley, both since drained by gorges. A lake was also held up in the Seathwaite valley by a moraine at Thornthwaite, a mile south of those at Rosthwaite. North of the Rosthwaite moraine a lake was impounded by a moraine of an earlier period of retreat which crosses the valley at Frith Wood and Castle Crag. The alluvial bottom of this drained lake is a very marked feature of the valley at the present time. In Newlands Vale the edge of the Borrowdale ice impounded a lake, which cut an overflow channel at 470 feet O.D. through the spur of Barrow, into Coledale, which in turn was drained by a channel through Braithwaite How at 360 feet O.D. In the Vale of Newlands, lake muds have been found, and the present limit of cultivation of the land marks almost exactly the limit of the lake. In Borrowdale a series of large lateral channels served to carry the impounded drainage of the westerly tributary valleys along the ice margin to the north, where about Grange in Borrowdale this water found its way to the sub-glacial drainage of the main glacier.

One other feature of the glaciation it may be well to mention, and that is the abundance of tarns in the area. These have been well described by Professor J. E. Marr.[1] Many of these are true rock-basins, well-glaciated, now drained in many cases by a rock gorge of late glacial or post-glacial origin. They afford material for a comprehensive study of cirque glaciation. Throughout Borrowdale the side valleys hang to the main valley, and the tributary streams enter the main valley by a series of cascades usually starting in a gorge breaching the rock-lip of the tributary valley. Almost all these valleys have evidence of filled-in or drained tarns in their upper parts and have been modified by cirque glaciation.

The present distribution of farms and hamlets throughout the district has been determined by the distribution of moraines and lake phenomena, the lake floors providing excellent meadows and the moraines forming the well-drained sites of most of the houses and hamlets.

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[1] *Q.J.G.S.*, vol. li, 1895, p. 35, and *Q.J.G.S.*, vol. lii, 1896, p. 12.

REVIEWS.

OUTLINES OF THE OCCURRENCE AND GEOLOGY OF PETROLEUM. By I. A. STIGAND. pp. x+246. London: Charles Griffin and Co., Ltd., 1925.

THE author of this book has had a very wide experience of oil geology in all parts of the world, and this fact is manifested in nearly every page by apt illustration taken from actual examples of the points under discussion. The reader, therefore, feels confidence in the value of the writer's opinions on many controversial points. The book is quite elementary in character, and is well calculated to give to students a sound and balanced view of the special problems that arise in this rather difficult field. There are no lengthy descriptions of the geological structure of particular fields, but a sane and lucid discussion of both theoretical and practical matters. After a general introduction Chapter II gives an account of the various theories regarding the origin of bitumen in general, which the author believes to be, in general terms, due to decomposition of organic matter, mainly marine and especially micro-organic, accompanied by rapid accumulation of argillaceous deposits, the oil being at a later stage transferred to porous strata. It is considered that bituminous substances are very widely distributed, but only become conspicuous under certain favourable conditions. Chapter III discusses the stratigraphical distribution of oil and gas, while the next three chapters mainly deal with structural and tectonic considerations. Chapter VII, of nearly fifty pages, is devoted to direct indications of the presence of petroleum. It may perhaps be suggested that both here and elsewhere a little too much space is devoted to an elaborate classification and nomenclature of the various recognized types of solid bitumens.

A valuable appendix, contributed by Dr. Max Mühlberg, deals with geophysical methods as applied to oil-finding, with a useful bibliography. Finally there is a very good and unusually complete index.

This book may be recommended to all readers who wish to obtain in a handy form a guide to the general principles of oil geology, without paying too much attention to local detail, which is often merely confusing instead of being instructive.

BISMUTH ORES. By R. ALLEN. pp. 62. Price 3*s.* 6*d.* ANTIMONY ORES. By E. HALSE. pp. 102. Price 5*s.* Imperial Institute Monographs. London: John Murray, 1924.

THESE two monographs follow the lines of the earlier volumes of this useful series. Incidentally we are glad to note that the authorities have reverted to the former practice of giving the names of the authors, a procedure which unfortunately has not always been followed. The plan of these monographs is now so well known that it is hardly necessary to enter into details in either case. Besides the geological portions, the amount of information given as to technical applications and economic conditions of each metal is very useful. The production of bismuth has now fallen to almost nothing, except from Bolivia, while in antimony China is far ahead of all other countries.

SUMMARY OF PROGRESS OF THE GEOLOGICAL SURVEY OF GREAT BRITAIN FOR 1923. pp. i–iv+1–172, text-figs. 1–14. Pub. H.M. Stationery Office. Price 4*s.*

THE energies of the Officers of the Geological Survey at the present time seem to be directed chiefly to work on the Coalfield areas, and though it is regrettable that this necessitates suspension of the primary 6-inch survey of the Highlands, it must be conceded that it is of the highest importance that areas containing coal, iron, or other minerals of economic importance should be resurveyed and the results of such survey published as speedily as may be.

In the London and S.E. area the most important work achieved has been the completion of the survey of the Marlborough sheet: a colour-printed map together with a memoir by Mr. Osborne White has just been published.

In the N. of England, by the application of modern methods of zonal stratigraphy most interesting results have been arrived at concerning the lateral variation of the Millstone Grit. This is shown in some vertical sections, and forms the subject of a special appendix by L. H. Tonks and W. B. Wright. In the Cumberland district it is satisfactory to read that in spite of many difficulties attending the interpretation of the Whitehaven Coalfield a sequence has now been obtained by which the general structure can be made out.

In Scotland, the first survey of Ardnamurchan has been completed, and work in all the Coalfield areas pushed forward rapidly, notably in the case of Ayrshire, of which 22 6-inch maps were published in 1923.

The printing and general " get up " of the report is good, and there is a welcome drop in the price !

G. L. E.

INDIA'S MINERAL WEALTH. By J. COGGIN BROWN. (India of To-day, vol. iv.) pp. 121. Oxford University Press, 1923. Price 3*s.* net.

THE author of this small volume, printed at Bombay and published at Oxford, is well known as one of the chief authorities on the mineral production of India. He has given in this small compass a judicious mixture of mineralogical, geological, and statistical information on the numerous and interesting natural products of that great Empire and its dependencies, which should be of great value to those who desire to obtain such information in an accessible and reliable form. As is well known, many of the Indian mineral occurrences present features of unusual scientific interest, having a considerable bearing on mineralogical and petrogenic theory, and in most cases references are given to the original publications in which such matters are dealt with. Apart from coal, the chief mineral products of the Indian Empire are gold, manganese, and petroleum, the last-named mainly from Burma, while the outputs of lead, mica, silver, tin, and wolfram are all worthy of mention.

ORGANIC ADAPTATION TO ENVIRONMENT. By G. E. NICHOLS, L. L. WOODROFF, A. PETRUNKEVITCH, W. R. COE, G. R. WIELAND, C. O. DUNBAR, R. S. LULL, and E. HUNTINGTON. Edited by M. B. THORPE. pp. xviii+312. Six plates and 34 figures in text. New Haven: Yale University Press; London: Humphrey Milford and Oxford University Press, 1924. Price $4 or 18*s*. net.

THIS book is the result of a symposium formed by eight members of the staff of Yale University with a view to obtaining precise and correlated data bearing on the subject of organic adaptation throughout the earth's past history and at the present time. The first four chapters dealing with vegetable life, the Protozoa, the mutation problem, and the environment as a stabilizing factor, are of general biological interest. The last chapter on "Environment and Racial Character" is mainly anthropological, and attempts to synthesise the standpoints of the anthropologist, the historian, the ecologist, and the geographer. In the remaining three chapters the adaptation of the organism is considered from the palaeontological point of view, and here we meet with some remarkable contrasts. Dr. Wieland shows that the evolution of vegetable life has been a slow process, for plants appear to have had more capacity for resisting their environments than for being influenced or moulded by them. Professor Dunbar's account of the Cephalopods and that of the Dinosaurs by Professor Lull, on the other hand, illustrate the extraordinary diversity of form and structure and corresponding variety of functional adaptation displayed by two dominant groups of animals, one molluscan and one vertebrate, in response to changing conditions. These chapters are of arresting interest, and contain many new ideas, among which we note the suggestion that the Dinosaurs became extinct as a result of endocrine deficiency. The book is well worthy of the Yale University Press.

F. H. A. M.

REPORTS AND PROCEEDINGS.

Geologists' Association.

Friday, 6th March, 1925.

The Succession and Structure of the Borrowdale Volcanic Series as developed in the area lying between the Lakes of Grasmere, Windermere, and Coniston. By J. J. Hartley, M.Eng., M.Sc., F.G.S., Assoc.M.Inst.C.E.

The main object of the paper is to trace the effect of the well-known Coniston and Windermere faults on the Borrowdale Volcanic Series. The effect of these faults on the outcrop of the Coniston Limestone Series is clear, but further north, in the volcanic rocks, they are more difficult to follow.

A petrological succession for the volcanic rocks in this district is first established, and the tectonic structure, with the nature of the folding and faulting, is investigated.

The general result of the work appears to show that the effect of the faulting on the Borrowdale Volcanic rocks has been to produce relative displacements of a vertical rather than of a horizontal nature, and that these rocks were folded along lines running nearly N.–S. before the deposition of the Coniston Limestone Series.

The Zones of the Oxford Clay near Peterborough. By E. Neaverson, D.Sc., F.G.S.

The zonal sequence in the Oxford Clay around Peterborough is broadly interpreted by means of the sections in numerous brickfields; notes are given on the general facies of the faunas. The sandy Kellaways Beds underlying the Oxford Clay are now exposed N.W. of Werrington. The local base of the Oxford Clay (*conlaxatum* zone) is the equivalent of sandy Kellaways Beds in Wiltshire. Shales immediately superjacent (*elizabethae* zone) contain flattened ammonites similar to the well-known Christian Malford forms. The presence of the *coronatum* zone is established by specimens of *Erymnoceras reginaldi* (Morris). Relatively unfossiliferous clays are referred to the *castor* zone. These horizons are worked around Fletton and west of Whittlesey. Higher zones, at Eye Green and south of Whittlesey, contain pyritic ammonites, viz. *duncani* zone with Cosmocerates, *athleta* zone with Peltocerates, *lamberti* zone with Quenstedtocerates. A fault running E.–W., through the brickfield at Eye Green brings the *castor* zone into juxtaposition with the *lamberti* zone. Reasons are given for supposing that the March and Chatteris "islands" are Ampthill Clay rather than Kimmeridge Clay.

The Permian of Durham. By C. T. Trechmann, D.Sc., F.G.S.

The communication includes a map of the County of Durham and the S.E. corner of Northumberland, showing the Permian divided up into its various beds, the Yellow Sands, the Lower

Magnesian Limestone, the Middle Magnesian Limestone, including the Bryozoa reef and the bedded dolomites that lie to the east and west of it, and the Upper Magnesian Limestones comprising the Cannon Ball Limestone and the uppermost Hartlepool and Roker Series. There is also a section of the southern portion of the Durham coast; the northern half was sketched out by the late Dr. Woolacott some years ago. A description of the faunal peculiarities of the Bryozoa reef is given and the gradual extinction of the mollusca and other animals that went to build it up is indicated. A comparison with the Permian of East Germany is instituted, and it is shown that the Durham Permian is more like that of Germany than it is that of the rest of England. A tabular list of fossils, the result of some 20 years' collecting in the district, is supplied.

Friday, 1*st May*, 1925.

Aspects, Geological and otherwise, of the Everest Expedition. By N. E. Odell, A.R.S.M., F.G.S.

A lecture illustrated by lantern slides.

The Petrography of the Portland Sand of Dorset. By M. P. Latter, B.A., F.G.S.

The sharp contrast in lithology between the western deposits which have been subjected to folding prior to that which took place over the whole district in Post-Cretaceous times, and the beds in East Dorset is reflected in the sharp contrast in the petrography of these two areas. This paper, while giving an account of the general petrography of the Portland Sand of Dorset from results obtained in the field by a comprehensive method of sampling, has for its object rather the interpretation of these petrological data, in so far as they reveal the natural history of the sediments themselves, including under this term their source of origin and conditions of deposition. A natural petrographical assemblage can be defined for the Portland Sand, which differs in many respects from any mineral suite which may characterize other formations, and, if only for this reason, a distinctive stratigraphical term (other than Upper Kimmeridge Clay), such as "Portland Sand", is justified and best retained for this deposit, which elsewhere is represented by normal Kimmeridgian.

EDINBURGH GEOLOGICAL SOCIETY.

17*th December*, 1924.

1. The Hypothesis of Continental Drift. By Mr. H. M. Cadell, D.L., J.P.

Mr. Cadell gave an address on Wegener's theory of the Origin of Continents and Oceans, which had been brought forward some years ago, although the published account of the hypothesis had been translated for English readers only this year. The so-called Displacement theory was based on the theory of Professor Suess—that the earth was practically a solid globe of a heavy metal, such as iron or nickel, on which there was a skin of lighter rock designated *Sima*, resembling a heavy basic lava containing silica and magnesia (hence the term). This Sima covering behaved like a viscous fluid, such as pitch or sealing-wax, only it was infinitely more viscous. On this skin there lay a lighter superficial layer made up chiefly of *si*lica and *al*umina, and hence designated *Sial*. The Sial, however, only covered part of the Sima, and originally was all collected together in one huge continental island. After the Carboniferous and Permian Periods large cracks appeared, and the cake of Sial began to break up like ice on a pond. Under the influence of solar attraction the western part gradually sailed away over the Sima ocean, underlying the water, and the principal rift widened out until it finally grew into the great Atlantic. The South American continent fitted into West Africa like the parts of a jig-saw puzzle, and Wegener maintained that his theory explained this coincidence and many other things hitherto obscure to geologists and geographers. In like manner North America had once formed part of Europe, and Australia had been tucked into part of what is now the Indian Ocean. The position of the poles relatively to the Sial had shifted at various times, and South Africa had in the Permian age been close to the South Pole. Wegener maintained that in Northern Europe the great disruption had been of comparatively recent date, and had taken place after the Ice Age, the Atlantic Ocean, indeed, still being in process of slow widening. Mr. Cadell said the theory, although highly interesting, had various weak points, and many objections to it had been raised by British geologists. He illustrated the subject by means of a globe and a model covering of movable Sial, in which he produced rifts and displacements, to show how far the theory could be demonstrated on a small scale.

2. Exhibition of Mesozoic Fossils from the Boulder Clay of Caithness. By Mr. D. Laing, Mey, Caithness, and Mr. W. Manson, H.M. Geological Survey.

The two fossils exhibited were obtained from the boulder-clay in the district of Mey, North Caithness. One specimen is an echinoderm of the genus *Conulus*, referable to *Conulus abbreviatus*, from the Upper Chalk. The other specimen is part of an Ammonite of the genus *Paltopleuroceras*, from the upper part of the Middle Lias.

The shelly boulder-clay of Caithness was produced by land-ice coming mainly from the south-east. The ice-mass had travelled east out of Sutherlandshire and Ross-shire, but, meeting with the great Scandinavian ice-sheet in the Moray Firth basin, it was forced to move in a northerly and finally north-westerly direction, thus passing over the Caithness plain. Part of the evidence of this movement is the finding of many fossiliferous blocks from the Ross and Sutherland Mesozoic rocks in the boulder-clay of Caithness.

There are neither Middle Lias nor Cretaceous strata found cropping out on the eastern seaboards of Sutherland and Ross, but the occurrence of *Conulus* and *Platopleuroceras* in the boulder-clay of Caithness seems to show that such rocks may be present upon the floor of the Moray Firth.

21*st January*, 1925.

1. On Needles of Rutile in the Test of *Bathysiphon argenteus*. By Mr. Allan B. Dick. Illustrated by Lantern Slides.

Mr. Allan B. Dick, London, contributed a short paper describing the occurrence of rutile needles in the test of *Bathysiphon argenteus*. These foraminifera occur at intervals all round the Scottish coast, and in the North Sea right across to Norway. The finest specimens have been obtained in comparatively shallow water (10 fms.) off Millport. The wall of the tubular chitinous test of this animal contains numerous rod-shaped bodies or spicules which previous observers have suggested might be secretions specific to the organism. These are now shown to be rutile needles.

2. Note on a Specimen of *Echinocorys* lined with Calcite and Barytes Crystals. By Dr. H. H. Read, H.M. Geological Survey. Illustrated by Lantern Slides.

Dr. H. H. Read of H.M. Geological Survey described a hollow specimen of the echinoderm *Echinocorys*, from the Chalk of Birchington, Kent, which, on being broken open, was found to be almost completely lined with crystals of calcite, in optical continuity with that of the plates, each plate bearing a crystal. Further, on the internal base of the specimen, there were many rosettes of tabular crystals of barytes, a mineral probably new, and in any case rare, in the Chalk.

3. The Heavier Accessory Minerals in the Granites of Scotland. By William Mackie, M.A., M.D., D.Ph. Illustrated by lantern slides.

The chief result of this inquiry, which embraced the examination of 178 specimens of granite and other granitic rocks collected from as many localities throughout Scotland, is to show the wide distribution of the mineral monazite, which has only twice previously been recorded—and these in single crystal occurrences—from Scottish rocks. Of the rocks examined 85 showed the presence of monazite—in a number of instances in comparative abundance. The mineral is practically confined, as was found by O. A. Derby many years ago to obtain in the case of the granites of Brazil, to the more acid granites and does not occur in hornblendic and sphene-bearing granites. With the exception of that of the Ross of Mull, neither has it been found in any granite to the north-west of the Caledonian Canal nor in any of the granites of Shetland. The distribution of some 25 other heavy minerals in the granites of Scotland, in addition to two others as yet unidentified, is given in detail.

23rd January, 1925.

1. Alpine Structure. By Professor Léon W. Collet.

The idea of great recumbent folds is now universally accepted in Alpine interpretation. In 1905, Argand applied it in detail in elucidating the Pennine Alps about Zermatt, and demonstrated six vast recumbent folds with Palaeozoic cores and a Mesozoic envelope. The Matterhorn itself is a fragment of one of these Palaeozoic cores partially isolated by erosion.

Staub, in a magnificent publication that appeared at the end of 1924, shows that Argand's recumbent folds continue into N.E. Switzerland, and are there covered by six other great repetitions of old and young rocks interleaved (the Austrides); in these upper structures the style is particularly reminiscent of the N.W. Highlands. The Pennine Nappes reappear in the Austrian Alps only in "windows", as for instance at the Tauern.

Argand has, in imagination, straightened out the great folds of the Pennine Alps, and reconstituted the geography of the period of their growth. He has, in fact, followed the development and advance of individual ridges in the old-time sea. He adopts Haug's geosynclinal theory, which the lecturer claimed as destined to remain for all time the basal conception of mountain structure. Termier has shown how the Alps originated through the approach of the two sides of the Alpine geosyncline, functioning like the jaws of a vice. Argand has announced that the thrust masses of the Austrian Alps belong to Africa; they represent a marginal portion of Africa over-riding Eurasia. These views are accepted by Staub and the lecturer. Obviously, the structure of the Alps lends strong support to Wegener's theory of drifting continents.

LIVERPOOL GEOLOGICAL SOCIETY.

10th March, 1925.

1. Notes on the Petrology of Penmaenmawr Mountain. Part II, The Acid Segregations and Veins. By H. C. Sargent, F.G.S.

The Acid Segregations or *Schlieren* consist of irregular streaks and patches varying from a few inches up to 3 or 4 feet in length. In colour they are white, grey, or green; often with a green matrix mottled with white spots. They occur only on the higher horizons and mainly in the interior of the *massif*.

The veins exhibit the same variations of colour as the segregations. They occur throughout the entire thickness of the intrusion, but are most abundant on the higher horizons.

The petrography in both segregations and veins is the same. Quartz and orthoclase, generally in micrographic intergrowth, are the dominant constituents. Original prehnite, ilmenite, and apatite are always present. Alkaline plagioclase is rarely absent. Analyses are quoted showing the content of silica to be ten to twelve per cent in excess of that in the normal rock.

The variations in colour are due to differential alteration of felspar. Chloritic material, amphibole minerals, epidote and prehnite are among the alteration products.

The mineralization of the eastern shoulder of the mountain, Graig Lwyd, is described. The following minerals occur in thin veins and incrustations: axinite, prehnite, pectolite, talc, zoisite, epidote, calcite, and quartz.

The differentiation processes leading to the formation of the foregoing features are discussed.

2. The Stratigraphical Horizon and Field-Relations of the Holywell Shales and " Black Limestone " of North Flintshire. By H. C. Sargent, F.G.S.

This paper records the result of preliminary field-work carried on last summer by Mr. E. Montag, F.G.S., and the author.

The " Black Limestone " is that on the west of the Chert-beds in the Prestatyn and Teilia area.

Considerable collections of goniatites have been made, and the undermentioned zones in Mr. W. S. Bisat's classification are indicated.

Zone.	*Locality.*	*Lithological Horizon.*
G. (*Gastrioceras*) *cancellatum*	Panton Hall Valley (Holywell Shales). Talargoch Mine. Heap, Meliden (Black Limestone).	Shales below the Rough Rock.
R. (*Reticuloceras*) *inconstans*	Walwen Valley (Holywell Shales).	Top of Sabden Shales.
E. (*Eumorphoceras*) *bisulcatum*	Near Holywell (Holywell Shales).	Base of Sabden Shales.
Pseudobilingue	Walwen Valley (Holywell Shales).	Upper part of Bowland Shales.

Lower zones have not yet been definitely determined from the goniatite fauna, but *Posidonomya* beds are present in both the Holywell Shales and the " Black Limestone ".

The zones already determined show that the Holywell Shales should not be referred to the Coal Measures.

The " Black Limestone " is homotaxial with the Holywell Shales, which overlie the Chert-beds on the east, and it is, therefore, younger than the Chert. It is faulted down against the Chert in the Prestatyn area.

The " Black Limestone " transgresses the Chert on the west, and rests directly on the Carboniferous Limestone.